A Systems Approach to Identify Skill Needs for Agrifood Nanotechnology: A Mixed Methods Study

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Dedication

To Ivy, Eli and Kekeli for all the time I was not present in their lives even though I was mostly physically present. For their understanding, this thesis is dedicated!

Abstract

The purpose of this study was to identify skill needs for the emerging agrifood nanotechnology sector and to determine how agricultural education can contribute to human resource and workforce development for this sector. As nanotechnology continues to advance in food and agriculture, there is the need for pragmatic decisions as to how to prepare the workforce. This mixed methods study incorporated disparate fields of systems and complexity theories; nanoscience and nanotechnology; science policy; agricultural education; human resource development and workforce education. The study followed a four-step process involving different methods and approaches. The first phase involved a comprehensive systematic evidence review (SER) and analysis of the literature. This phase of the study also helped to identify key experts and formulate questions for the in-depth and semi-structured interviews and also quantitative survey instruments. A comprehensive stakeholder analysis was done using primary data obtained from experts.

The second phase of the study used multi-criteria approaches for value elicitation (which included qualitative and quantitative data) from key stakeholders and experts to identify current and future skill needs in the agrifood nanotechnology sector. The third phase of the study included quantitative analysis, Qualitative Systems Analysis (QSA) and Strategic Flexibility Analysis (SFA) of evidence from the literature review and the multi-criteria value elicitation of experts and stakeholders. The final phase of the study created a generic systems model from the quantitative analysis, QSA and SFA to describe holistically the current and future skill needs for agrifood

nanotechnology workers as well as how educational practice and policy can meet these needs.

The main conclusions from this study are that: (1) future shortages and skills gaps in agrifood nanotechnology are expected to increase but at the same time there is still quite a lot of uncertainty about future developments and impacts of nanotechnology in the agrifood sector to accurately determine future demand and supply of agrifood nanoskilled workforce. (2) Extra demands in high qualified workers with a background in sciences and engineering (PhD, MSc) will be needed. (3) STEM education at the K-12 levels is even more important than ever and that K-12 nanotechnology programs should be a seamless part of the overall STEM initiative. And most importantly STEM education should not be devoid of employability skills. (4) In addition to various types of technical skills that come with advances in any technology, and thus nanotechnology, employability skills and competencies such as problem solving and ability to work in an interdisciplinary context are considered very important.

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Chapter 1 – General Aspects of Study

Before you continue any further to read this dissertation please take 20 minutes to enter the strange world of nanoscience - it can take you into atoms and beyond the stars: http://www.youtube.com/watch?NR=1&feature=endscreen&v=70ba1DByUmM

Nanotechnology offers unprecedented potential for the well-being of society through advances and innovation. The U.S. National Science Foundation (NSF) predicted in the year 2003 that the total global market for nanotechnology products and services will reach $1 trillion by 2015 (NNI, 2000a). This represented nearly 10% of the gross domestic product of the U.S. at the time (currently approximately 7 percent) and it is estimated that 2 million workers will be needed to support this growth (Roco & Bainbridge, 2003). The breakdown of the estimated workforce needs by jurisdictions is as follows (Allen, 2005): 0.8-0.9 million – USA; 0.5-0.6 million – Japan; 0.3-0.4 million – Europe; 0.2 million – Asia Pacific (excluding Japan); 0.1 million – other regions. In addition, it has been projected that nanotechnology will create another five million jobs worldwide in support fields and industries (Roco, 2011; 2003). Several studies have predicted a surge in workforce demand to an estimated 20 million by 2020 (Cleary, 2009; Hullmann, 2006; Roco, 2003) and many scholars have written about the potential for nanotechnology in the marketplace (Horn, Cleary & Fichtner, 2009; Roco, 2011; Yawson, 2011a).

This potential is also creating an unprecedented need for scientific, ethical, legal, economic, political, and social dialogue to address the swiftness and complexity of the nanotechnology enterprise (Yawson, 2011b). For example, little is “known about how the skill and workforce needs of employers are evolving in real time, in particular industries, and within specific regional labor markets" (Horn, Cleary, Hebbar, & Fichtner, 2009, p.2). It is thus important to understand the types of skills, knowledge, and educational credentials that workers will require as the demand for nanotechnology workers increases (Horn, Cleary, Hebbar, et al., 2009). However, current research on the nanotechnology workforce and the educational preparation required to succeed in nanotechnology careers lacks the requisite information. Moreover, there are several uncertainties associated with forecasts of labor demand and supply (Black, 2007).

Background of Study

There is very little empirical research related to the nanotechnology labor market and even less comparative work in other emerging high-tech fields (Yawson, 2010). The United States Bureau of Labor Statistics has no data on the nanotechnology workforce. To date no industrial classification (NAICS–North American Industry Classification System) exists for nanotechnology (Black, 2007). Moreover, "the data used to assess competitiveness in mature technologies and industries, such as revenues and market share, are not available for assessing nanotechnology" (Sargent, 2008, p.1). In order for agrifood nanotechnology to reach its full potential, the discipline will require in-depth research to provide these employment and industry data. The relevant data can be obtained if the skill needs for agrifood nanotechnology workforce are known.

Academic research and comparative analyses geared towards early recognition of qualifications can help avoid current and future skill deficiencies (Yawson, 2010). Timely and appropriate selection of methods and study designs permit forecasts to be made for specific occupations, sectors and fields of activity (Spath & Buck, 2006). To prevent disproportionate distribution of skills and shortages of skilled workers on the labor market, the early identification of skills needs is an important pursuit (Steeger, 2007). The logical consequence of early identification of new skills is a continuous alignment of education, training, and the effective design and development of relevant curriculum to meet the emerging workforce needs of nanotechnology experts in agriculture.

Overview of Agrifood Nanotechnology and Identification of Skill Requirements

The History of Nanotechnology

Historians of science and technology have always traced the development of a particular idea or invention back to what McCray referred to as "singularity," that is, lone inventor or small teams who led or whose ideas led to a paradigm shift in the scientific enterprise (Yawson, 2011b). For genetic engineering and related applications, there is Mendel, and then Watson and Crick, with the discovery of the double helix decades later; for electrical engineers, Shockley, Brattain, and Bardeen's invention of the transistor (McCray, 2005); and for the Internet, Vinton Gray Cerf, Bob Kahn, and Leonard Kleinrock; these are a few classic examples. For nanotechnology, it can be pointed to an exact point in place and time—"the evening of 29 December, 1959 when Richard P. Feynman gave an after-dinner speech in Pasadena to members of the American Physical Society" (McCray, 2005, p. 181) where he delivered his classic, "Plenty of Room at the Bottom," in which he proposed the idea of studying things at the atomic level (Feynman, 1960), an idea that would come to be called *nanoscience* and *nanotechnology*. The use of the term *nanotechnology* as technically defined is, however, attributed to Norio Taniguchi of the Tokyo Science University in a 1974 conference on Production Engineering (Taniguchi, 1974), whereas the commercial definition is attributed to K. Eric Drexler as expressed in his book *Engines of Creation* (Drexler, 1986).

The history of the development of nanotechnology cannot be full without mention of the invention of scanning tunneling microscope in 1982, and the atomic force microscope in 1986, which enabled the direct study, manipulation, and engineering of the physical structure and properties of materials at the atomic scale to be done (Foley & Hersam, 2006). In January 2001, President Clinton established the "National Nanotechnology Initiative: Leading to the Next Industrial Revolution" (NNI, 2000b, p. 3).

Agrifood Nanotechnology

The potential applications of nanotechnology in the agrifood system were first addressed in 2003 in a roadmap published by the United States Department of Agriculture (USDA, 2003). The predictions were that the entire agrifood supply chain would be affected by advances in nanotechnology and bring fundamental changes to the agrifood industry. The application and use of nanotechnology in agriculture can be categorized into direct and incidental use.

The fact that there are nanomaterials in high speed computing and these computers are used in agriculture; and "to the extent that nanotubes are incorporated into tires, they might appear on farm vehicles" may affect agriculture and thus be classified as incidental uses of nanotechnology in agriculture (Thompson, 2010, p. 164).

For direct applications of nanotechnology in agriculture, Kuzma and VerHage, (2006) have extensively discussed the potential benefits and risks of agrifood nanotechnology. According to their report, there are several potential applications of agrifood nanotechnology in the areas of precision crop and livestock production. Nanomaterials being developed to enhance the precise use of agro-chemicals are of particular interest. An example is a nanotechnology-based pesticide under development that will only become active when inside the target insects (Downey, 2006).

Nanotechnology has the potential for providing more efficient application of pesticides, fertilizers and other agro-chemicals to alleviate poverty through improved food security, land use, and environmental sustainability (Kuzma & VerHage, 2006). In relation to functional foods, the potential engineering of nanomaterials to detect and block harmful substances in food, such as unwanted cholesterol or allergens, from affecting the body will also be highly beneficial. The development of nanomaterials that can selectively enter cell walls could bring significant nutritional and health benefits (Downey, 2006). However, some of these nanomaterials are inherently different by their nature in terms of chemical reactivity and physical properties from naturally occurring substances, and could have unexpected side effects (Downey, 2006).

Nanotechnology is becoming increasingly important for the food sector, and advances have already been made in the areas of food packaging and food safety. The incorporation of nanomaterials into food packaging is expected to improve the barrier properties of packaging materials and should thereby help to reduce the use of valuable raw materials and the generation of waste (Sozer & Kokini, 2009). Edible nanolaminates may also have potential uses in encapsulation systems for environmental protection

(Chen, Weiss, & Shahidi, 2006). These applications could be used in fresh fruits and vegetables, bakery products and confectionery, where they might protect the food from moisture, lipids, gases, off-flavors and odors (Sozer & Kokini, 2009). Naturally-occurring biopolymers and other biological molecules of nanosize scale, such as oligosaccharides or polysaccharides and proteins, can be used for the encapsulation of vitamins, prebiotics and probiotics formulations, and for drug-delivery systems or nutraceuticals (Sozer & Kokini, 2009) and as target-specific-recognition agents that could be used as biosensors in foods (Tarver, 2006) and in precision agriculture. These biosensors are envisaged to be used as detectors of pathogens and other contaminants in food and for tracking food products to help facilitate food recalls for example. These innovative devices and techniques being developed are to facilitate the preparation of food samples and their precise and inexpensive analysis (Chen et al., 2006). From this point of view, the development of nanosensors to detect microorganisms and contaminants is a particularly promising application of agrifood nanotechnology. Nanosensors can also be used in the formulation of food additives such as flavors and antioxidants (Chaudhry et al., 2008). This is aimed at improving the functionality of these additives while reducing their concentration.

The applications of nanotechnology in agriculture and the manufacture of food products come with its potential risks. The United States is a clear leader in nanofood research and development (R&D) and nanotechnology research in general. Globally billions of dollars have been invested in nanotechnology research and applications in all fields including medicine, rural water supply, energy, agriculture, defense, biodiversity and environment (Yawson, 2011a). If these trends should continue, nanotechnology is expected to become a prime driver and focus of innovations in the agrifood system in this decade and beyond.

The foregoing raises fundamental questions about how the current and future human resource and workforce in the agrifood industry are educated. “A core task in developing effective education and training programs is in mapping work skills to curriculum standards” Sabelli et al., (2005, p. 32)

Skill Needs Identification and Workforce Development

Emerging technologies by their nature demand a set of fundamental skills that can either be specific or general in nature at different levels of occupations, with the ability to promote innovation and enhance research and development (European Centre for the Development of Vocational Training, (CEDEFOP), 2009). Therefore, failure to identify specific skill gaps and skill shortages may significantly limit the development and application potential of the new field of nanotechnology (Zukersteinova, 2007). Early detection of new qualification demands is an efficient approach to ascertaining which qualification standards industries and workers must have. Emerging technologies such as nanotechnology frequently set off high growth for particular sectors of the economy and create new jobs at different occupational strata including jobs for researchers and scientists but also for an array of technicians and specialists with secondary, post-secondary and non-university tertiary educational qualifications (Poteralska, Zielinska, & Mazurkiewicz, 2007).

Academic research and comparative analyses geared toward recognition of early qualification can help avoid current and future skill deficiencies (Spath & Buck, 2006). Timely and appropriate selection of methods and study designs permit forecasts to be made for specific occupations, sectors, and fields of activity. “Early detection research results for new technologies contribute significantly to human resource development and strengthen the innovativeness and competitiveness of companies and the whole economy” (Spath & Buck, 2006, p. 19).

Skill needs identification and workforce development for the agrifood nanotechnology present its unique challenges, due to the different actors involved: From the farmers and farm hands to the managers and factory hands to the marketing and sales staff of the food industry. This requires a whole systems approach in dealing with this challenge and thus the importance of this study. It is however, evidently clear that within the scope of time and space of a doctoral thesis and the limitations imposed by funding, it is impossible to specifically identify skill needs and the future skill needs in all individual categories of the agrifood sector, and this study lays no claim to even attempt doing that. The focus of this study is to present from a systems perspective, the identification of generic skill needs in the agrifood sector as a first step towards the development of the human resources for the sector.

Introduction of nanotechnology and nanoscience to the classroom comes with it different kinds of challenges. The multi-, trans-, and interdisciplinary nature of nanoscience and nanotechnology make them very different from the traditional disciplines contained in the current grade 7-12 curriculum. This requires removal of the curricular demarcations that exist between the science disciplines (Yawson, 2010). The practice where science tends to be taught with strict divisions between disciplines may need reformation with the advent of nanoscience (Stevens, Shin, Delgado, Krajcik, & Pellegrino, 2007). The arbitrary sequence with which disciplines are taught with little to no reference between them may have to change. Successfully incorporation of nanoscience into grade 7-12 curriculum is also a challenge. It is necessary to first identify where it might be appropriate to introduce nanoscience concepts into the agricultural science curriculum in order to support student learning (Yawson, 2012; 2010). Another challenge is professional development of agricultural science teachers. The nascent and emerging nature of agrifood nanoscience and nanotechnology as a discipline necessitates that agricultural science teachers be introduced to new concepts and strategies and learn how to teach the traditional curriculum differently by finding and then communicating connections between the disciplines to the students (Bryan et al., 2007).

Introduction of nanotechnology into the agricultural education curricula will pose its unique challenges. Some agricultural science teachers have traditionally express serious anxiety in introducing the physical sciences into their curricula. Hubert and Leising, (2000) for example, have reported that agricultural science student teachers "reported high levels of anxiety associated with teaching agricultural mechanics prior to and during their student teaching" (p.24). These anxieties may even be exacerbated with introduction of nanotechnology.

Transfer of these technologies to industry and in agricultural extension should be of national priority and will further serve to educate the public and future workforce about the potential advances offered by nanotechnology for agriculture and food systems (Yawson, 2012). In higher education, any curriculum developed for agrifood nanotechnology should therefore be based on good theoretical foundations and a balance of knowledge competencies drawn from mathematics and the physical sciences together with the chemical and biological sciences integrated with applied sciences (particularly material science, microelectronics technology, instrumentation technique, among others) commerce, management, social sciences and the humanities (Yawson, 2012). This poses a different challenge to agricultural educators. Introducing agrifood nanotechnology qualification contents into professional and vocational training will be decisive in maximizing nanotechnology's potential (Yawson, 2010). Unfortunately, issues of nanotechnology workforce development have currently seen little input from agricultural education and human resource development professionals

Theoretical Framework

This study is an interdisciplinary study involving disparate fields of systems theory; nanoscience and nanotechnology; science policy; agricultural education; human resource development and workforce education. The research is based on theory that accounts for the dynamic aspect of systems modeling, complexity theory, skill identification and workforce development. This interdisciplinary approach is predicated on the conception that "disciplinarity is no longer the dominant system for creating and organizing knowledge, and that knowledge creation is now trans-disciplinary, more reflexive, non-linear, complex and hybridized" (Yawson, 2009, p.9). Lubet, (2009) in discussing his pioneering role in the field of Disability Studies in Music described this scholarly approach as the tenets of "epistemology of interdisciplinarity" (p. 120). This predication is also in conformity with the recommendation by Greiman and Birkenholz, (2003) that AgEd doctoral students must be encouraged "to engage in interdisciplinary projects to prepare them for future contributions as faculty members" (p. 75).

The prevailing and emerging trend in the literature for skill needs identification for new and emerging technologies is a more holistic approach which combines a variety of methods and generates more reliable and vigorous results. This study is therefore based in and relies on elements of systems theory, complexity theory, and nonlinear dynamics in order to open up new possibilities for field work (Patton, 2002). In addition, emerging methodologies (mixed methods approaches) are similarly necessary to identify skill needs that inform workforce development.

Chaos theory and its offshoots, complexity theory and complex adaptive systems (CAS), are underlined by the features of nonlinear dynamical systems theory representing a new and distinct generation of thought. These theories maintain that "relationships in complex systems, like organizations, are non-linear, made up of interconnections and branching choices that produce unintended consequences and render the universe unpredictable" (Tetenbaum, 1998, p. 21). Complexity theory posits "that some events, given our knowledge and technology, are unknowable until they occur, and may indeed be unknowable in advance" (Schneider & Somers, 2006, p.354). Determining the skills needs for an emerging sociotechnical system such as the agrifood nanotechnology sector accentuates the importance of using nonlinear dynamical systems as the underlying theory of the study.

Three key interrelated aspects of complexity theory relevant to this study are: Non-linear dynamics, in which structures are characterized by high states of energy exchange with the environment and extreme instability (Hickman, 2010); chaos theory which is nonlinear, deterministic (rather than probabilistic), sensitive to initial conditions, and continuous irregularity in the behavior of the system (Taleb, 2007); and, adaptation and evolution, in which an ability to modify or change is evidenced through a process of interdependent self-organization, and negative and positive feedback processes among individuals or sub systems (Schneider & Somers, 2006).

Systems theory offers the opportunity for experimentation and reflection and thus can facilitate the complete understanding of the complex environment in which educational policy makers operate (Fisher, Norvell, Sonka, & Nelson, 2000). The identification of skill needs in the agrifood nanotechnology will involve a high level of complexity in which to model and to understand their practicality and their effectiveness. Complexity exists partly due to the emergent as well as the multidisciplinary nature of nanotechnology and the issues of existing workforce development in Agriculture, Science, Technology, and Engineering (ASTE). Through system dynamics modeling, educators, policy makers and other stakeholders may gain insight into the causal factors that may create the skill gaps and shortages. Knowledge of how causal factors affect skill needs patterns in agrifood nanotechnology development may assist industry, educators, academics and policy decision-makers in strategic planning and the development of human resources.

The nature of the problem this study will address is such that quantitative approach or qualitative approach, individually, will not be enough to develop multiple perspectives and a complete understanding of the problem. The research questions guiding this study require different methods of analysis from different disciplines. And finally, dialecticism represents the paradigmatic or philosophical orientation in which this research is grounded, a worldview that bridges post-positivist and social constructivist worldviews, pragmatic perspectives, and transformative perspectives

(Greene, 2007). The choice of a mixed methods design for this study is therefore informed by dialecticism and this complex set of theoretical and conceptual orientation. Therefore, the incorporation of non-linear systems dynamics/mixed methods modeling into this study based on systems and complexity theories is to:

- Identify factors that may enhance or obstruct the identification of agrifood nanoskill needs and also understand the intricate interrelationships that exist between skill requirements, educational policy and curriculum development, and agrifood nanotechnology workforce development;
- Understand the dynamics between emerging nanoskill needs and agrifood nanotechnology curriculum development and explain how the interaction of these factors over time can lead to successful workforce development or its failure;
- Learn what characteristics that may be peculiar to agrifood nanotechnology instruction and teaching in the face of new skill requirements for the agrifood sector;
- Identify policies and programmatic intervention points that may serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector;
- Simulate the potential impact of those interventions and establish which combinations of policies and programs are likely to be most effective for agricultural educators and education policy makers in general in their role of preparing and developing the human resources for the agrifood sector.

Justification of study

The growing convergence of nanoscience and nanotechnology, information and communication technologies (ICTs), biotechnology, synthetic biology, gene editing technologies, and a host of related existing and emerging scientific disciplines is creating a challenge for workforce development. Specifically, there is an increasing need to identify skills and qualifications for these emerging fields (Yawson, 2011b). Unfortunately, issues of nanotechnology workforce development have currently seen little input from agricultural education and human resource development professionals and academics. The academic community is not treating the preparation of the workforce for emerging opportunities in nanotechnology with the urgency it deserves (Uddin & Chowdhury, 2001; Yawson & Kuzma, 2010). The inevitability of the profound impacts nanotechnology will have on the agrifood system should thus concern agricultural educators.

This is not to say that education and workforce development discussions are missing completely in this dialogue. A number of articles have appeared in the literature on nanotechnology workforce development (e.g., Cleary, 2009; Fazarro & Trybula, 2010; Feather & Aznar, 2010; Foley & Hersam, 2006; Fonash, 2001; Roco, 2003; Trybula, *et al*., 2009; Yawson, 2012; 2011a-b; 2010). There are also a number of national and local initiatives in nanotechnology education. A significant example of such initiatives is the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) funded by the National Science Foundation. NCLT provides teachers with educational resources to help with their classroom activities on nanotechnology-related concepts (National Nanotechnology Initiative [NNI], 2009a-b).

What is missing is the voice of HRD professionals, educators, and education policy professionals and experts. Issues of agrifood nanotechnology workforce development in particular have seen no input from education and human resource development professionals and agricultural educators. It is rare to find any article on agrifood nanotechnology in most leading educational journals. As a result, a dialogue of the needs for workforce, skill, and human resource development related to nanotechnology in agrifood industries is conspicuously absent (Yawson, 2011b).

The history of development and progress is replete with periodic, significant scientific discoveries or revolutions that radically affect the way of life of the human enterprise (Kuhn, 1996). Examples of such scientific revolutions (Kuhn, 1996) include the industrial revolution, the airplane, the computer, and the internet. Various organizations and many national governments have predicted that developments in nanotechnology will represent a "new paradigm" shift and may have an impact far greater than the impact of the internet, "changing protocols in many different fields and even creating whole new industries that will influence the way we interact with people, businesses, and other machines and systems" (Kessler & Charles, 2007, p. 401). One area that would be impacted most is the agrifood system where new nanotechnology-related skills and competencies will be required of stakeholders, employees and leaders involved in the entire agrifood chain. Labor market demands that result from this paradigm will cause various types of impacts on the educational system.

It is important for research to determine skill requirements via a longer-term perspective that provides information on new qualifications, competences and requirements that have not yet been defined by statistics and industrial classifications

(Tessaring, 2009). There is always a time lag between a technological innovation or emergence of a scientific revolution and the juncture when the first potential workforce leaves the educational system with the required skill profiles. This time lag demands that early identification and anticipation of future skill needs for the emerging agrifood nanotechnology sector become a priority in educational and training policies to avoid future skills gap (Tessaring, 2009).

In the 1960s and 1970s the determination of educational and skill needs, job projections, job supply, and job demands was very rigid (Tessaring, 2009). These rigid projections and determinations have changed dramatically in the last three decades due to what Tessaring (2009) described as "increasing openness, flexibility, complexity and, therefore, also uncertainty" (p. 147) associated with industrialized societies. Major trends and changes like "globalization and internationalization of economies, job markets and even of education and training systems, demographic transition and the transformation towards an information and knowledge based society" (Tessaring, 2009, p.147) have all contributed to the changes in the last three decades.

However, most of these changes are still embedded in linear way of workforce development. It has been contended that computerized and econometric models for skills demand and supply projections as the only way of forecasting labor needs is insufficient (European Centre for the Development of Vocational Training [CEDEFOP], 2008). It has further been explained that the fundamental question for future oriented research into skill needs is not: "'How many people in this profession will be required in 5 to 10 years?' but: 'Which professions and what kind of new qualifications and skills are needed?' and: 'What qualities of the workforce will be in demand?'" (CEDEFOP, 2008, p.6). The argument therefore is that these new research questions require dynamic, non-linear, non-mechanistic approaches to build on existing computerized workforce forecasting models (CEDEFOP, 2008). The foregoing is what makes this study important and relevant; and also justifies the use of systems theory and complexity theory as the underlying theories for the study.

Problem statement

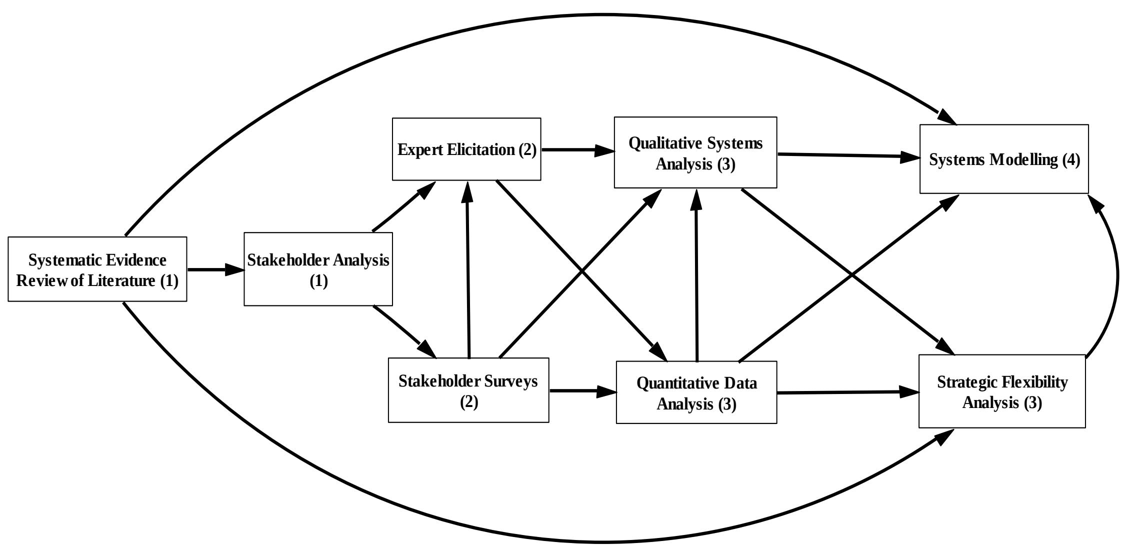
The lack of early identification of skills needs for emerging agrifood nanotechnology sector will cause an imbalance of skills and shortages of workers on the labor market. The objective of this study is to determine the current and future skill needs for the emerging agrifood nanotechnology sector. The main research question guiding this study is: ***What are the future skill needs in agrifood nanotechnology?*** The study also addresses the following related questions:

1. Who are the stakeholders in agrifood nanotechnology workforce development and how do they perceive skills shortages and gaps in the sector?
2. Based on an understanding of skill shortages and gaps, how can educational practice and policy meet these needs?
3. What policies and programmatic intervention points can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector?

Conceptual Framework

This is a multi-phase, mixed methods study design (Creswell & Plano-Clark, 2010) based on systems theory and complexity theory. The study follows a four-step process involving different methods and approaches. The first phase marked (1) in the schematic diagram in Figure 1 involves a comprehensive systematic evidence review (SER) and analysis of the literature. This phase of the study will also help to identify key experts, conduct stakeholder analysis, and formulate questions for in-depth and semi-structured interviews.

Figure 1. *Schematic Representation of Research Framework*



The second phase of this study, marked [2] in the schematic diagram below, will use multi-criteria approaches for value elicitation including surveys and semi-structured interviews with key stakeholders and experts to identify current and future skill needs in agrifood nanotechnology sector.

The third phase of the study (marked [3] in the schematic diagram) will include Qualitative Systems Analysis (QSA); Quantitative Data Analysis (QDA); and Strategic

Flexibility Analysis (SFA) (a scenario analysis method) of evidence from the literature and results from the multi-criteria value elicitation of experts and stakeholders. The final phase of the study (marked [4] in the schematic diagram) is to create a systems model from the QDA, QSA and SFA to describe holistically the current and future skill needs and the important links, interrelationships and apparent themes and patterns identified in the prior phases.

Outline of Dissertation

As I have described in the preceding section on the conceptual framework of the study, the research methodology comprises a disparate but interlinked number of research activities, including literature review of methods and concepts associated with the study, systematic evidence review of the literature to answer the main research question, surveys and interviews (multicriteria value elicitation) of experts and stakeholders, and QDA, QSA and SFA of the results. The dissertation brings all together, structured as follows:

- Chapter 2 is the literature review: In this chapter the key terms, concepts and methods that framed the overall context of this research are reviewed. This review is a little different from the standard literature review for dissertations where related worked done in the area of research is reviewed. This is because, the study also uses systematic evidence review of the literature as a methodological approach in answering the main research question, where research evidence was collected from relevant existing literature based on predefined criteria.

- Chapter 3 is the description of methods of data collection: This chapter presents the different methods and approaches used in collecting data for this study. The methods and data collection measures were designed to answer the research questions the study set out to address.
- Chapter 4 focuses on the results of the study. The results of the systematic evidence review, stakeholder analysis, and the multicriteria value elicitation of experts' and stakeholders' opinion are reported
- Chapter 5 presents the analysis and discussions of the results of the study: The chapter analyzes the evidence from the systematic review; describes both qualitative (QSA) and quantitative (QDA) data analyses; and uses a Strategic Flexibility Analysis (SFA) – a scenario analysis approach to discuss the data obtained from the various sources. All the analyses ultimately culminated in the development of a generic systems model which is also described in the chapter.
- Chapter 6 is the concluding chapter of the dissertation: This chapter summarizes the answers to the research questions by giving the most important conclusions of the study and translates the outcomes in a number of recommendations.
- Appendices: There are several appendices to this dissertation which detail the questionnaires and survey instruments for the multicriteria elicitation; some of the more granular results which were not reported in the main documents, and other documents of interest to the study.

Chapter 2 – Literature Review

This chapter presents the reviewed literature on the key terms, concepts and methods that framed the overall context of this research. This is done in order to give clarity and situate this study in a bounded frame and curtail on ambiguity as much as possible. The chapter also reviews the literature on existing research methods for skill needs identification.

Review of Key Terms and Concepts

The following section defines, discusses and/or describes the key terms that are used throughout the study and concepts that serve as the foundational basis of this thesis. The terms and concepts as outlined below do not follow any particular order of importance or criteria.

Nanoscience and Nanotechnology

There are several definitions of nanoscience and nanotechnology in the literature. Many of these definitions are derived by government agencies and have been modified with time to address the issues of concern and interest to society, as articulated through the technological, commercial, populist, legal, social, and ethicist communities (Romig Jr et al., 2007). The most cited definition is that of the National Nanotechnology Initiative (NNI) of the United States:

> Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. *(NNI, 2009;2000a*-b)

A nanometer is one-billionth of a meter. The NNI put this measure in perspective using a sheet of paper as an analogy: The thickness of a sheet of paper is approximately 100,000 nanometers thick. The dimensions between approximately 1 and 100 nanometers are the nanoscale (NNI, 2000a-b). At this scale, unusual physical, chemical, and biological properties can emerge in materials. These properties tend to differ in very significant ways from the normal properties of bulk materials and single atoms or molecules (NNI, 2000a-b). The term ‘nanotechnology’ is a bit of a misnomer because nanoscience and nanotechnology developments and applications are situated in a variety of disparate fields (Yawson, 2010). Some organizations and experts in the field usually prefer to use the plural form, nanotechnologies, a typical example being the Royal Society (2004). In this study ‘nanotechnology’ is used as a collective term for all nanotechnologies as it is used by the NNI.

Agrifood

The term agrifood describes activities encompassing the supply of agricultural raw materials to the production of food and its distribution. It is a ‘compromise’ term coined to gain acceptance as a common terminology from those reluctant with the use of the term ‘agribusiness' to describe the business of agriculture and related activities inside and outside the farm gate, including transformation of commodities into food (Ginns, 2002). The term agrifood reflects accurately both the process of production and the product - food that eventually is consumed. Agrifood system includes the occupational profiles clustered under what the United States Bureau of Labor Statistics refers to as Agriculture, Food and Natural Resources (AFNR) and defines the cluster as “the production, processing, marketing, distribution, financing, and development of agricultural commodities and resources including food, fiber, wood products, natural resources, horticulture, and other plant and animal products/resources"(ONET, 2013).

Agrifood goes beyond primary production (farming), and includes trade, industry (such as food and feed manufacturers), private services (such as banks, insurance companies, sectorial organizations and associations) and public services (legislation and regulation on product quality and public health) for agriculture and food production (Mulder, 2006, p.93). The term has gained a worldwide acceptance and use; and is officially used by governmental and intergovernmental agencies including the USDA, World Bank and the United Nations Food and Agricultural Organization (FAO); and the emerging preferred term in academic and practitioner literature. In Canada for example, the Federal government has a Department of Agriculture and Agrifood. The use of the term started in the 1980's but became popular around 1995 and it use peaked around 2006. Follow this link to see Google Books Ngram Viewer of agrifood.

An attempt to describe all niches that constitute the workforce in the agrifood system will require hundreds of pages. "The workers in this complex have diverse occupations at different levels, from the low educated subsistence farmer to the PhD in bionanotechnology or geoinformation systems" (Mulder, 2006, p.95). This workforce includes farmers and farm hands, scientists, seed suppliers, crop insurers and bankers, food chemists, ethanol producers, packaging engineers, food safety and quality control experts, agro-ecologists, veterinarians, meat inspectors, risk assessors, contract negotiators, educators, shippers, grocery and retail store suppliers, institutional food buyers, and among several others (National Research Council, NRC, 2009).

The listing of over 100 occupations by the International Standard Classification of Occupations (ISCO-08, 2008) and over 170 by the Occupational Information

Network (O*NET) is a testament to the diversity and sheer numbers of occupations encompassed by the agrifood sector. The challenge of HRD and agricultural education is to be able to "recruit and cultivate the workforce of the future for this diverse and dynamic universe of enterprises made up of individuals, businesses, and institutions which are to work together across disciplines, language gaps, physical distances, and national differences to achieve their goals" (NRC, 2009, p.3) all of which have been predicted to be impacted dramatically as a result of emergence of nanotechnology (USDA 2003).

Agricultural Education

It is my contention that the use of the term 'Agrifood Education' will better serve to describe all what is done in agricultural education and appropriately reflect the challenges faced by 21st Century agricultural educators. Agriculture can mean different things to different people. To some, it has been limited to production agriculture - that is, farming. While farming remains a vital and central part of agriculture, what defines 21st - century agriculture is much broader, encompassing a range of natural and social science disciplines (NRC, 2009, p. 14).

This makes agricultural education one of the most multidisciplinary fields of study. In addition to developing and training the human resources for the entire agrifood systems, it has the unique role of training the trainers for the entire pipeline of human resources and workforce – that is teacher education for the agrifood sector. Agricultural education includes Technical and Vocational Education Training (TVET), Career and Technical Education (CTE), adult education, and liberal education. The NRC, (2009) has contended that:

> Many faculty members do not have experience in the broader food and agricultural enterprise (let alone in traditional production) that would enable them to give students a ‘real-world’ interpretation of the ideas, concepts, and skill sets they need to acquire to be effective in the diverse agricultural workplace (p. 14).

Greiman and Birkenholz, (2003) have also stated that:

> The changing landscape of agricultural research suggests that faculty success in the future will be dependent on a different set of job performance skills than was required in the past. Therefore, agricultural education doctoral programs that prepare future faculty members need to recognize and accommodate the changing expectations (p.75)

This problem may be exacerbated with the emergence of nanotechnology, and HRD and agricultural education has a huge role to play in this regard. The preparation of future faculty who are equipped to train the future workforce should be of priority. The first step towards this goal is to be able to identify the skills that are needed and will be needed in the workplace and the farms to appropriately develop faculty suitable in developing such workforce. Identification of the skill needs will also help determine how CTE, TVET, adult education and all other aspects of agricultural education should be handled. A reason this study on skill needs identification for agrifood nanotechnology is of critical importance.

Skill

The use of the term ‘skill’ in everyday discourse renders it quite insignificant, even supremely mundane. However, the dictionary definitions of skill and the review of historical and contemporary literature on the concept of skill reveal the complexity of the concept which may require a complete study on its own. Attewell (1990) described the sociological studies of skill as situated within “four separate theoretical schools, each with a different understanding of skill and consequently a different agenda for research” (p. 445). These schools-of-thought have Positivism, Ethnomethodology, Social

Constructionist School, or Marxist Theory as their foundational philosophies. I make no attempt to situate this study in any of these philosophies, as it will be restrictive and create a bounded conception.

Having said that, I must place on record that I subscribe to a research approach of dialecticism – pragmatist, postmodernist, postnormal science or what I prefer to call 'non-linear epistemology'- research orientation. My orientation is predicated on my belief that the normal science, as defined by Kuhn, (1996) is the routine work of disciplinary scientists "puzzle solving" in their paradigm. Normal science research espouses the facts of the established theory but does not necessarily challenge it or test its assumptions (Batie, 2008). Although the linear epistemology of normal science is the dominant epistemology in the fields of my specializations and "its usefulness is implicit in its widespread impact on models and on their use, a linear epistemology has several limitations, including a tendency to privilege particular Western cultural and masculine worldviews, short-term measures, and effects close to the organization" (Jayanti, 2011, p. 101).

The concept of skill used in this study is, therefore, based on Spenner's (1990) description which takes a holistic view of skill and not situated in any particular philosophical orientation. Spenner, (1990) described skill as:

> Human capabilities in response to job demands stemming from a broad range of purposes and substantive questions including issues such as how technological change alters the quality and quantity of work, ergonomic and productivity considerations in job design and redesign, the measurement of comparable worth *vis-a-vis* comparable pay (including a growing number of private sector consultants in court litigation), optimal workplace organization and the labor process, human resource training models and planning, overeducation and underemployment, projections of future labor force configurations and needs, task structure and human motivation, and task organization in relation to stress, health, psychological disorder, and personality, to name only some areas of investigation (pp. 404 -405).

Most often than not, the mention of skill within the confines of education or human resource development directs our thinking to TVET or CTE. However, as has been described by Spenner, (1990) identification of skill especially for technological change encompasses broader outlook than just TVET or CTE.

Based on the above definition, ‘skills shortages’ as used in this study refers to a situation where firms cannot obtain in the labor market sufficient supply of the required skills. A skill shortage occurs when an employer has a vacancy that is hard-to-fill because applicants do not possess the requisite skills, qualifications or experience (Gelderblom et al., 2012). The use of “skills gaps “in this study refers to the qualitative mismatch between the supply or availability of human resources and the requirements of the labor market. Skills gaps are created when workers have inadequate skill types/levels to meet their employers’ objectives or when new entrants to the labor market are apparently trained and qualified for occupations but still lack some of the skills required (Strietska-ilina, 2008). The use of “employability skills”, refers to attitudes, behaviors and values like communication, creativity, problem-solving, among other attributes. In comparison to technical skills, employability skills are more stable and predictable (Gelderblom et al., 2012). In some of the literature employability skills and personal skills are used interchangeably (Gelderblom et al., 2012). Overtoom, (2000), defined employability skills as the “transferable core skill groups that represent essential functional and enabling knowledge, skills, and attitudes required by the 21st century workplace… necessary for career success at all levels of employment and for all levels of education” (p. 2).

Technical skills refer to knowledge in scientific fields like nanosciences and nanotechnology and their specific branches like agrifood nanotechnology. Technical skills include also methodological competences or the ability to handle technical processes. Identification of technical skills needs in say a 20 - year time frame is a hazardous and complex task, taking into account that technologies evolve very quickly, with development paths often being erratic and not easily predictable (Gelderblom et al., 2012).

Agrifood nanotechnology and nanotechnology in general as with most emerging fields and rapidly evolving disciplines in science and technology, requires a broader skill set, with the collection of young and talented scientists as the main engine of growth and development (Yawson, 2010). The proper management of this core group of talents through training and mobility opportunities is important in the success and sustainability of these new fields. The norms and trends of various times determine how each generation of workforce is educated. What will be needed in the coming years is an education matrix - the congruence of the theoretical and practical aspects of trans-disciplinary education (Yawson, 2010). There is the need for empowerment with the set of skills that will provide the platform for effective analysis and action in scientific, technological, leadership, communication, environmental, ethical, economic, and legal policy to address the increasingly complex issues arising from the emergence of nanotechnology (Yawson, 2012; 2010) what I collectively refer to as ‘nanoskill’.

While the need for training scientists is not new for any emerging technology, in addition to the need for scientists, a larger than any other industry pool of skilled technicians and farm workers would be needed in the case of agrifood nanotechnology (Yawson, 2010). Strong societal requirements and consumer acceptance are the driving force of nanotechnology development. Qualified experts and strong demand on education in the multi-, trans- and interdisciplinary field of nanotechnology is a logical consequence of this process (Yawson, 2012; 2010). This is the reason why this study is taking a systems approach to skill needs identification instead of a linear focus on one aspect of the skills requirements.

As a logical consequence of the many changes nanotechnology is predicted to bring into the agrifood system, it is anticipated that employers will seek growing sets of skills and perspectives in the people they hire (NRC, 2009). Clearly, people with global perspectives and concern for the environment increasingly will be in demand, as will those with rigorous scientific preparation in a variety of fields. But other skills are also essential, including problem-solving, critical thinking, team-building, leadership, communication, conflict and financial management, and thriving in diverse environments (NRC, 2009, p. 18).

Leaders and other employers in the agrifood system will look to community and technical colleges and universities as a source for workforce-ready graduates who have the skill-set necessary in meeting the new and emerging requirements of nanotechnology use and applications in agriculture. Employers will hire qualified students wherever they are. If agricultural educators fail to align their curriculum with the skill needs of agrifood industries in the wake of the emergence of nanotechnology, companies that traditionally employ graduates from colleges of agriculture may look elsewhere in the universities and colleges and may find better qualified students in other colleges throughout the university as a result of the trans-, inter- and multidisciplinary nature of nanotechnology.

Systems Theory

Systems theory has been variously defined in the literature. It is however, important that before systems theory is discussed the word ‘systems’ is defined. It is one of the most loosely used words both in everyday discourse and in academic literatures. It is defined as “a set of elements or components that work together in relationships for the overall good and objective (or vision) of the whole” (Haines, 2010 p. 2). All occurrences are interconnections of relationships among component parts of a system. Also referred to as general systems theory or systemics is the theory underlying the study of systems. Systems theory has a very long history but as an academic discipline its foundation is generally accredited to Karl Ludwig von Bertalanffy, an Austrian-born biologist's with his development of General System Theory (GST).

It is a trans- and interdisciplinary field that studies complex systems in nature, society, organizations, and science (Yawson, 2013). Systems theory is therefore a framework by which elements that act in concert to produce some result are studied. *Principia Cibernetica Web* defines systems theory as the “transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both the principles common to all complex entities, and the models which can be used to describe them” (Heylighen, 2000, webpage). One branch of systems thinking which will be used in this study is systems dynamics - a method to enhance learning in complex systems (Sterman, 2000, 2001).

Complexity Theory

One important aspect of a systems research is the complexity of systems. A complex system is defined as a system which is made up of interconnected parts that exhibit concerted properties as a whole which are different from the properties exhibited by the individual constituent parts when acting alone. A complex system is either a disorganized or organized complexity.

Yorks and Nicolaides (2006) in discussing the notion of centrality of ST&T to HRD theory, made a clear distinction between systems that are complicated and those that are complex (Yawson, 2013). "Complicated systems may appear complex but can be deconstructed and usually function in a linear way; complex systems may seem simple but are dynamic, ever interacting as they evolve in a nonlinear way" (Yorks & Nicolaides, 2006, p. 145). Systems with huge number of parts are mostly disorganized whereas organized complexity normally has limited components and a subject system that exhibit emergent properties.

There are different types of complex systems: Chaos theory and its offshoots complexity theory and complex adaptive systems (CAS), are underlined by the features of systems theory, although they may represent a new and distinct generation of thought (Yawson, 2013). These theories maintain that "relationships in complex systems, like organizations, are non-linear, made up of interconnections and branching choices that produce unintended consequences and render the universe unpredictable" (Tetenbaum, 1998, p. 21). Complexity theory posits "that some events, given our knowledge and technology, are unknowable until they occur, and may indeed be unknowable in advance" (Schneider & Somers, 2006, p.354). Complexity theory includes three interrelated elements that are not accounted for in General Systems Theory (GST). These are non-linear dynamics, in which structures are characterized by high states of energy exchange with the environment and extreme instability (Hickman, 2010); chaos theory which is nonlinear, deterministic (rather than probabilistic), sensitive to initial conditions, and continuous irregularity in the behavior of the system (Taleb, 2007); and adaptation and evolution, in which an ability to modify or change is evidenced through a process of interdependent self-organization among individuals or sub systems (Schneider & Somers, 2006).

Chaotic systems (random behavior): Chaos theory is one of the most misconstrued areas in systems theory. This may probably be that the word 'chaos' is a misnomer since it connotes disorder. Chaos systems theory is the theory underlying understanding the behavior of systems that exist between rigid regularity and randomness based on pure chance (Kellert, 1992; Levy, 1994). For any systems to be described as a chaotic system, it must be nonlinear, deterministic (rather than probabilistic), sensitive to initial conditions, and continuous irregularity in the behavior of the system (Kellert, 1992; Levy, 1994; Taleb, 2007; Williams, 1997).

Complex adaptive systems (CAS): CAS are special cases of complex systems. The diverse and multiple interconnected elements confer the complexity. The ability to evolve, transform and learn from experience confers the adaptive nature in such systems. There are several examples that can be listed for CAS, including: the stock market, manufacturing businesses, and any human social group or group-based endeavor in a cultural and social system, among several others including biological systems. There are several tools to study complex systems and these "tools for learning about complexity must also facilitate the process of systems thinking and policy design" (Sterman, 2001 p. 22).

Cybernetics: Like the broader systems theory itself, cybernetics has various definitions. Converging the various definitions, it can be described as the study of how information, communication, feedback, and control specifically functions within and outside a system (Heylighen, Joslyn, and Turchin, 2000). Major emphasis of the field of cybernetics have focused on describing the heterogeneity of interacting parts of a system such as complexity, mutuality, complementarity, evolvability, constructivity, and reflexivity (Heylighen, Joslyn, and Turchin, 2000; Ruona, 2008).

Existing Research Methods for Skill Identification Studies

The necessity to identify how skill needs develop is the result of the need for timely and reliable information which is essential for education program design, for the provision of counseling and guidance services, and for efficient human resource and workforce development, and policymaking at all levels including enterprise, local, state, and federal (Strietska-Ilina, 2006). All the various methods and approaches come with their pros and cons. Available methods for skill identification used by national governments, research centers and individual researchers vary widely. CEDEFOP (2008) has described these methods and approaches as ranging from:

> quantitative and semi-quantitative approaches such as econometric forecasting models (national level, sometimes allowing spatial disaggregation), surveys among employers, skills audits; to qualitative, such as Delphi method, case studies, focus groups, sector scouting and determining qualification requirements among trendsetting companies, and finally combined/holistic approaches, such as foresights, shared diagnosis, scenarios (including some proactive approaches to construction of the future – strategies, backcasting, etc.), observatories (sector, regional). Other approaches used include sector studies, alumni surveys and monitors, specific branch/type of activity/occupation/field of qualification studies, studies on skill requirements for specific target groups (unemployed, disabled, low/non-qualified, ethnic minorities, foreign workers) and so on (p. 12).

In a study to examine the labor market for the highly skilled in nanotechnology and the response of universities toward providing training, Stephan, Black and Chang

(2007) used what they referred to as “position announcements in nanotechnology” approach where online position announcements in *Science* and on-line sources were used as proxies to obtain information concerning nanotechnology skill demand. This approach which has its epistemological foundations in ethnographic studies has several limitations, as it does not account for announcements which were not made on-line or the sources used.

It has been contended that computerized and econometric models for skills demand and supply projections as a major and only way of forecasting labor needs have found it place in the archives (CEDEFOP, 2008). It has further been explained that “the prevailing question for future oriented research into skill needs is not: ‘How many people in this profession will be required in 5 to 10 years?’ but: ‘Which professions and what kind of new qualifications and skills?’ and: ‘What qualities of the workforce will be in demand?’” (CEDEFOP, 2008, p.6). The argument therefore is that “new functions and research questions require non-mechanistic approaches and enriched methods and, therefore, more than computerized manpower forecasting models” (CEDEFOP, 2008, p. 6). The prevailing and emerging trend in the literature is a more holistic approach which combines a variety of methods and generates more reliable and vigorous results.

Survey methods are currently the most popular approaches to skill needs identification. These different types of surveys offer acceptable depiction of skills profiles, projections and shortages and include employer surveys, skills surveys, workforce surveys, and opinion surveys. Enterprise survey is a popular method which has been used in different studies all over the world to provide first-hand information on skill needs directly from employers (Strietska-Ilina, 2006). It offers important information on the demand side of the labor market, providing valuable qualitative information on “skill and competence requirements, their changes, and skill gaps among specific categories (e.g. occupations, graduates with specific qualifications)” (Strietska-Ilina, 2006, p. 124). In addition, it provides a form of verification and validation of existing data and gives meaning to labor market processes and phenomena. Despite the popularity in its use, enterprise surveys have several limitations. Chief amongst them are low response rate as a result of several factors, and the often inflated or deflated data since most companies cannot always assess their current human resource situation and their future needs objectively for emerging technologies like nanotechnology.

Workforce surveys unlike enterprise surveys address the supply side of the labor market instead of the demand side and the subject of the surveys are the workforce rather than employers. Skills surveys on the other hand are used to obtain information on the nature of skill deficiencies rather than depicting skills profiles, projections and shortages. They are mostly used to obtain information on the needs for specific types of key, technical and generic skills (Slingenberg, Rademaekers, Sincer, et al., 2008). In certain studies survey methods have also been used to obtain opinions of experts on more qualitative data about trends, the current position and future possibilities (Slingenberg, et al., 2008). These form of surveys referred to as opinion survey have been used as part of expert elicitation studies. Expert elicitation forms an important component of the methodological approach to this study and thus detailed review of its use is presented. Based on the forgoing this study took a holistic approach modeled within the confines of academic research to serve as the basis for a new way of approach to skill needs identification.

Literature Review of Methods Used in the Study

The methods and approaches for this research are drawn from existing and emerging methodologies within three main disciplines of my specialization – Agricultural Education, Public Policy, and Human Resource Development and Workforce Education - in a mixed methods approach creating a novel research framework in the respective disciplines. This study uses systematic evidence review of the literature (Petticrew & Roberts, 2006; Yawson, 2013), expert elicitation (Van der Fels-Klerz, Goossens, Saatkamp & Horst, 2002; Yawson & Kuzma, 2011), stakeholder analysis (Varvasovszky & Brugha, 2000; Brugha & Varvasovszky, Z. (2000), scenario analyses (Malik, Yawson, & Hensel, 2009a, 2009b), and qualitative system analysis and systems dynamics approaches (Wiek, Lang & Siegrist, 2008; Yawson & Kuzma, 2010) to identify skill needs as the first step towards how to prepare, train, educate and develop the current and future workforce for agrifood nanotechnology. The following section reviews the literature on these methods and approaches to understand their use in this study.

Mixed Methods Research

Many definitions of mixed methods are available in the literature (Creswell, Klassen, Clark, & Smith, 2011; Johnson, Onwuegbuzie, & Turner, 2007). The different definitions come with them different nomenclature or taxonomical tags. The tags include *inter alia*: blended research, integrative research, multi-method research, multiple methods, triangulated studies, ethnographic residual analysis, and mixed research (Johnson et al., 2007). The disagreements in how it should be defined and named are not necessarily semantic; they reflect substantive differences over the proper way to categorize and understand methods, theoretical and philosophical foundations, and where the mixing occurs (Small, 2011). *Mixed methods research* (MMR) has become the most popular term used to describe this research approach. Johnson et al., (2007) analyzed 19 different definitions from leaders in the field of MMR and offered the following general definition:

> Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration (p.123).

One of the most popular definitions in the literature was provided by Creswell and Clark, (2011) as a research with a methodology involving a philosophical assumption that guide the direction of the design, collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in the research process. The Office of Behavioral and Social Sciences Research (OBSSR) of the National Institute of Health (NIH) commissioned a study to come out with *Best Practices for Mixed Methods Research in the Health Sciences* and the study proposed this definition which was accepted by the NIH as a research approach or methodology (Creswell et al., 2011, p.4):

- focusing on research questions that call for real-life contextual understandings, multi-level perspectives, and cultural influences;
- employing rigorous quantitative research assessing magnitude and frequency of constructs and rigorous qualitative research exploring the meaning and understanding of constructs;
- utilizing multiple methods (e.g., intervention trials and in-depth interviews);
- intentionally integrating or combining these methods to draw on the strengths of each; and,
- framing the investigation within philosophical and theoretical positions.

Mixed methods research starts with the assumption that researchers gather evidence based on the nature of the question and theoretical orientation (Creswell et al., 2011). MMR has been described as “the third methodological movement” (Johnson & Onwuegbuzie, 2004, p. 14) - a response to the age-old fruitless debates discussing the superiority and inferiority of quantitative versus qualitative research as a result of what has been termed the “paradigm wars’’(Feilzer, 2009, p.6). Mixing methods is, however, not new, and one can find mixed methods studies throughout the history of the social sciences. Many commentators, however, trace the origins of the modern work to the 1950s with publications from several different perspectives employing multiple methods in single studies (Small, 2011).

The issue of paradigm wars has however, not ended with MMR. Within MMR there are a lot of differences and critiques on mixing of paradigms. The different epistemological and ontological assumptions and paradigms associated with both qualitative and quantitative research have had a major effect on discussions in MMR as to whether the integration of the two is feasible and desirable (Ostlund, Kidd, Wengström, & Rowa-Dewar, 2011).

Mixed methods researchers apply and usually tend to make explicit diverse philosophical positions (Creswell et al., 2011). It has been argued that researchers who hold different philosophical positions may find MMR to be challenging because of the tensions created by their different beliefs (Greene, 2007). Table 1 adapted from Greene, (2008) offers one way of portraying the conceptually different stances on these issues in the literature. Some communities of scholars have therefore tended to find a common epistemological foundation for MMR as a standalone or alternative research tradition to quantitative and qualitative research.

Table 1. *Mixing Methods and Mixing Paradigms/Mental Models*

What Is the Character and Value of Traditional Paradigms or Mental Models?	What Most Importantly Guides Practical Inquiry Decisions?	Mixed Methods ‘‘Paradigm Stance’’
The assumptions of different traditional paradigms are fundamentally incommensurable. Each paradigm represents a coherent whole, which must be respected and preserved.	Paradigmatic assumptions	Because the assumptions of different paradigms are incompatible, it is not possible to mix paradigms in the same study. PURIST STANCE (Lincoln & Guba, 1985)
The assumptions of traditional paradigms are not fundamentally incompatible, rather different in important ways. These differences are valuable and should be preserved to maintain methodological integrity while expanding the scope of the study.	Paradigmatic assumptions, as well as context and theory	Because the assumptions of different paradigms are importantly different, methods implemented within different paradigms should be kept separate from one another. COMPLEMENTARY STRENGTHS STANCE (Brewer & Hunter, 1989; Morse, 2003)
The assumptions of different traditional paradigms are different in important ways and remain valuable, but paradigms themselves are historical and social constructions and so are not inviolate or sacrosanct.	Paradigmatic assumptions, as well as context and theory	Engaging dialogically with paradigm differences can generatively yield new insights and understandings. DIALECTIC STANCE (Greene & Caracelli, 1997; Maxwell & Loomis, 2003)
Historical philosophical incommensurabilities among paradigms are reconcilable through new, emergent paradigms, such as pragmatism, scientific realism, or transformation – emancipation.	The assumptions and stances of new paradigms that actively promote the mixing of methods, along with context and theory	ALTERNATIVE PARADIGM STANCE (Howe, 2003; Johnson & Onwuegbuzie, 2004; Mertens, 2003; Teddlie & Tashakkori, 2003; others)
The assumptions of various traditional paradigms are logically independent and therefore can be mixed and matched in varied combinations.	The practical characteristics and demands of the inquiry context and problem at hand Paradigms help us think better but do not themselves guide practice	A-PARADIGMATIC STANCE (Patton, 2002; Reichardt & Cook, 1979)
The assumptions of various traditional or emergent paradigms may well be embedded in or intertwined with substantive theories.	The substantive issues and conceptual theories relevant to the study being conducted Paradigms help us think better but do not themselves guide practice	SUBSTANTIVE THEORY STANCE

Source: Greene, (2008)

In pursuit of that epistemological foundation, authors have increasingly turned to pragmatism (Small, 2011). In more recent years the MMR community has generally seemed to coalescing around a common understanding that the various articulated positions, referred to as dialectal stances, bridge post positivist and social constructivist worldviews, pragmatic perspectives, and transformative perspectives to create the opportunity to transform these tensions into new knowledge through a dialectical discovery (Greene, 2007).

Trends in mixed data collection indicate that most contemporary empirical mixed methods studies have employed two or more different types of data or data collection techniques (Small, 2011). There are several categorizations of the different types of data collection in the literature (e.g. Creswell & Clark, 2011; Creswell, Clark, Gutmann, & Hanson, 2003; Fine & Elsbach, 2000; Johnson & Turner, 2003; Leech & Onwuegbuzie, 2007; Morse, 1991; Small, 2011). Small, (2011) grouped them into three main categories using the following criteria: “the purported motivations to combine different types of data, the extent of sequencing of the data collection, and the level of nesting of the multiple data sources” (p. 63).

In an attempt to clearly identify the types of mixed methods research, many authors have developed typologies or classification systems of mixed methods designs (Doyle, Brady, & Byrne, 2009). It has been contended that the main advantages of having a typology of mixed methods include: conveying rigor regarding the methodology, providing guidance and assisting in the development of language for mixed methods research (Bryman, 2006; Teddlie & Tashakkori, 2006).

Creswell et al., (2011) have suggested that to evaluate a mixed methods study, the researcher needs to:

- Collect both quantitative and qualitative data;
- Employ rigorous procedures in the methods of data collection and analysis;

- Integrate or mix (merge, embed, or connect) the two sources of data so that their combined use provides a better understanding of the research problem than one source or the other;
- Use a mixed methods research design and integrate all features of the study with the design; and
- Convey research terms consistent with those being used in the mixed method field.

These criteria are used by the NIH to evaluate MMR (Creswell et al., 2011).

Systematic Evidence Review

There is a wide array of approaches to literature review and research synthesis. Research synthesis is an umbrella term for the collection of approaches for summarizing, integrating and, in some cases, cumulating the findings of different studies on a particular topic or a specific research question (Davies, 2000). This broad range includes narrative reviews, integrative reviews, realist synthesis, vote-counting reviews, meta-analyses, best evidence synthesis, meta-ethnography and systematic evidence review (Davies, 2003; Davies, 2000; Gasteen, 2010; Petticrew, 2001). The simplest form of research synthesis is the traditional qualitative literature review, often referred to as the narrative review (Davies, 2003).

Traditional reviews offer a summary of a number of different studies and sometimes draw conclusions about a particular intervention or policy (Boaz, Ashby, & Young, 2002). Narrative reviews are almost always selective, if not arbitrary, in that they do not involve a systematic, rigorous and exhaustive search of all the relevant literature (Davies, 2000). In most instances, traditional/narrative reviews are opportunistic since they review only the literature that is readily available to the reviewer (Davies, 2000). Most narrative literature reviews deal with a broad range of issues related to a given topic rather than addressing a particular issue and usually examine the results of only a small part of the research evidence, and take the claims of authors at face value (EPPI, 2010; Cook, Mulrow, & Haynes, 1997). "Narrative reviews, primarily based on the experience and subjective judgment of the author(s) – often expert in the area – are the traditional approach to reviews of any body of knowledge" (Goodwin & Geddes, 2004, p. 249). Another major limitation of narrative reviews is that "they are almost always selective in that they do not involve a systematic, rigorous and exhaustive search of all the relevant literature using electronic and print media as well as hand-searching and ways of identifying the 'grey' literature" (Davies, 2003).

Narrative reviews seldom give full details of the processes and mechanics by which the reviewed literature has been identified and synthesized (Davies, 2003). It is also often not easy to determine how the conclusions were derived from the review (Davies, 2003; Tranfield, Denyer, & Smart, 2003). This lack of transparency makes it difficult to determine the selection bias and publication bias of narrative reviews (Davies, 2003; Thomas & Harden, 2003; Wright, Brand, Dunn, & Spindler, 2007).

Systematic evidence reviews are different from narrative reviews in that they attempt to deal with all of the limitations of narrative research (Cook et al., 1997; Thomas & Harden, 2003). SERs have developed in response to an increasing need for policy makers, researchers and education practitioners to have access to the latest research evidence when making decisions(Harden & Thomas, 2005). SERs are a rigorous and transparent form of literature review (ODI, 2012) and they incorporate the strengths of integrative reviews, vote-counting reviews, meta-analyses, best evidence synthesis, and meta-ethnography. It has been described as “the most reliable and comprehensive statement about what works if it is done well and with full integrity” (van der Knaap, Leeuw, Bogaerts, & Nijssen, 2008, p.49). SERs include identifying, gathering, synthesizing and assessing all available evidence, quantitative and/or qualitative, in order to generate a robust, empirically derived answer to a specific research question (ODI, 2012).

Key features of a systematic evidence review or systematic research synthesis are that (Dixon-Woods, 2006; EPPI 2007; Hemingway & Brereton, 2009):

- Explicit and transparent methods/protocol are used
- It follows a standard set of stages
- It is accountable, replicable and updateable
- Pre-specified, highly focused question
- Explicit methods for searching
- Explicit methods for appraisal
- Explicit methods for synthesis of studies

Although, SERs follow a standard set of stages, each particular study varies with how the stages are structured depending on the aim of the study and the research question. It has been argued that the key element of a SER is the process, rather than the specific method used to aggregate and interpret data (Gasteen, 2010). Generally developing SER requires the following steps.

- *Form a review team*: The first step is to develop appropriate review team. However, this step is not required if the study is by a single researcher for example a doctoral dissertation.

- *Define an appropriate research question*: As it is with most scientific research, a SER encourages the formulation of a clear question (Goodwin & Geddes, 2004). The definition of research question requires a clear statement of the objectives of the review, and these details are rigorously used to select studies for inclusion in the review (Hemingway & Brereton, 2009).
- *Develop a review protocol:* A review protocol specifies the methods that will be used to undertake a specific SER. The importance of defining the protocol from the onset is to reduce the possibility of researcher bias of selecting, for example, individual studies or the analysis may be driven by researcher expectations (Kitchenham, 2004).
- *Search the literature*: The published, unpublished, and grey literature is carefully searched for the relevant studies relating to the research question. The core essence of a SER is to find as many primary studies relating to the research question as possible using an unbiased search strategy. The rigor of the search process is one factor that distinguishes SERs from traditional reviews and the key components of the search strategy includes: Generating a search strategy, avoiding publication bias, and bibliography management and document retrieval (Kitchenham, 2004).
- *Assess the studies*: Having obtained the potentially relevant primary studies they need to be assessed for their actual relevance (Hemingway & Brereton, 2009; Kitchenham, 2004). Each study needs to be assessed for eligibility against inclusion criteria.

- *Extract data and combine results*: The objective of this stage is to accurately record the information researchers obtain from the primary studies. This aggregation of findings is called evidence synthesis(Hemingway & Brereton, 2009). The type of evidence synthesis is chosen to fit the types(s) of data within the review. The type of data is categorized depending on what the systematic review inspected. For qualitative data, then a meta-synthesis is conducted (Sandelowski & Barroso, 2003). If a homogenous quantitative data were inspected then meta-analysis is used (Crombie & Davies, 2009). Alternatively, if both quantitative and qualitative mixed methods data are the evidence assessed, then narrative summaries are used (Hemingway & Brereton, 2009).
- *Place the findings in context and report the review*: It is important to communicate the results of a systematic review effectively by discussing the evidence to put them into context. Usually systematic reviews are reported in at least two formats: In a technical report or in a section of a PhD thesis; and in a journal or conference paper (Kitchenham, 2004).

There are also a number of problems associated in conducting and using, SERs. Conducting a rigorous, trustworthy and generalizable systematic review is difficult and time intensive. It requires careful scientific consideration at inception, meticulous and laborious searching, as well as considerable attention to methodological detail and analysis before it truly deserves the badge ‘systematic’(Hemingway & Brereton, 2009). Dixon-Woods, (2006, p.10) listed the following challenges with SERs:

- Much more problematic when you have a messy question or messy forms of evidence

- Promissory nature creates conditions for disappointment
- Claim that proceduralization of method confers scientific credibility is not defensible *for all types of question*
- It does produce a certain type of narrativization of the evidence which does have benefits, but also has limitations *for some types of question*
- *For some types of question*, valorisation of procedure produces a method that is robust to “the author”, and stifles necessary elements of creativity, insight, and flexibility

However, the limitations posed by these problems, pale in comparison to traditional reviews and other reviews if used independently. Most of the problems associated with SERs can be mitigated with additional processes such as critical interpretive synthesis (CIS) which is sensitized to issues raised by conventional systematic review methodology (Dixon-Woods, 2006). Systematic reviews have much to offer the educational community in terms of providing unbiased evidence from a wide range of studies of educational policy and practice (Davies, 2000).

Stakeholder Analysis

The literature offers a wide variety of definitions as to who is a stakeholder. There is, however, little disagreement on what kind of entity can be a stakeholder (Mitchell, Agle, & Wood, 1997). A stakeholder is an entity who has something to gain or lose through the outcomes of a planning process, project, or policy formulation and implementation; and can be organizations, groups, departments, structures, networks or individuals. Stakeholders include interests groups who are affected by the issue or those whose activities strongly affect the issue; those who possess information, resources and expertise needed for strategy formulation and implementation; and those who control the implementation of the various responses (FAO, 2007).

Stakeholder Analysis (SA), is an analysis tool for assessing different interest groups around a policy issue or intervention, and their ability to influence or be influenced by the final outcome (FAO, 2007). Varvasovszky & Brugha, (2000) described Stakeholder Analysis as:

> An approach, a tool or a set of tools for generating knowledge about actors – individuals and organizations – so as to understand their behavior, intentions, interrelations and interest; and for assessing the influence and resources they bring to bear on decision-making or implementation process (p. 338).

Schmeer, (1999), described SA as "a process of systematically gathering and analyzing qualitative information to determine whose interests should be taken into account when developing and/or implementing a policy or program"(p.3). Grimble and Wellard, (1997) defined SA from systems perspective as "a holistic approach or procedure for gaining an understanding of a system, and assessing the impact of changes to that system, by means of identifying the key actors or stakeholders and assessing their respective interests in the system" (p.175).

SA originated in the fields of management studies and business administration (Brugha & Varvasovszky, 2000), but has found wide applications in political science, engineering, public policy, development studies and environmental studies (Billgren & Holmén, 2008). Billgren and Holmén, (2008) have observed that, depending on the scholar's academic interests; SA can take off in various directions. Walker et al., (2008) argued that these may be influenced by the researcher's ontological position and therefore the researcher at the onset of the analysis should declare what influences his/her perceptions.

Table 2. *Different Definitions of Who Is a Stakeholder*

Source	Who is a stakeholder	Area of research
Bowie, (1988, p. 112)	‘‘without whose support the organization would cease to exist’’	Business management
Bracke, Greef, & Hopster,(2005, p.34)	‘‘…any group or individual who can affect or is affected by the behavior of the system’’	Agrifood Policy
Buanes, et al, (2005, p. 211)	‘‘...any group or individual who may directly or indirectly affect—or be affected—...planning to be at least potential stakeholders.’’	Natural resource management
Clarkson, (1995, p. 106)	‘‘...persons or groups that have, or claim, ownership, rights, or interests in a corporation and its activities, past, present, or future.’’	Business management
FAO, (2007, P.1)	"...a person who has something to gain or lose through the outcomes of a planning process or project."	Agrifood Policy
Freeman, (1994, p. 46)	‘‘can affect or is affected by the achievement of the organization’s objectives’’	Business management
Gass, Biggs, & Kelly, (1997, p. 122)	‘‘...any individual, group and institution who would potentially be affected, whether positively or negatively, by a specified event, process or change.’’	Natural resource management
Grimble & Wellard, (1997, p. 175)	‘‘...any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system...’’	Natural resource management
Montgomery, (1995, p.2)	‘‘...persons, groups or institutions with interests in a project or program.’’	International development
(Roco & Bainbridge, 2007)	“An organization, person, or category of people that has a material interest in a pending policy decision and thus arguably should be involved in some way in the decision process”.	Nanotechnology Policy
Rowlinson & Cheung, (2008, p.613)	“…any individuals or groups which can affect organization or project performance or which are affected by the achievement of the organization’s or project’s objectives.”	Project Management
Schmeer, (1999)	“…are actors (persons or organizations) with a vested interest in the policy being promoted…”	Health Policy
Varvasovszky & Brugha, (2000, p. 341)	‘‘...actors who have an interest in the issue under consideration, who are affected by the issue, or who—because of their position—have or could have an active or passive influence on the decision making and implementation process.’’	Health Policy
Walker, Bourne, & Shelley, (2008, p. 648)	“…individuals or groups who have an interest or some aspect of rights or ownership in the project, and can contribute to, or be impacted by, either the work or the outcomes of the project”	Project Management

Stoney and Winstanley, (2001) argued that researchers should first clarify their position with regard to their beliefs and positions on who can be viewed as valid stakeholders so that their biases and chosen ontological perspective are clear.

Stakeholder analysis is a relatively simple analytical tool or approach and usually follows a 4-step process of Specification, Prioritization, Mapping (Visualization) and Engagement. Depending on the project or issue at stake there are varying sub-stages under each of these four broad steps.

Stakeholder Specification – This is the stage where stakeholders are defined and identified in relation to the specific issue under consideration (FAO, 2007). This stage is extremely important to the success of the analysis (Schmeer, 1999). The stakeholders are identified and then categorized into groups based on defined criteria indicating how they are affected or their influence on the issue under consideration or outcome of the project under consideration (Walker et al., 2008).

Stakeholder Prioritization – Time, scope of the project, finances and other resources available to the study or project are the main reasons for this stage of the SA approach. Since these resources are limited, the list of stakeholders to be interviewed must be prioritized (Schmeer, 1999). The stakeholder prioritization is undertaken by considering three factors that can assess the relative importance of stakeholders(Elias, Cavana, & Jackson, 2002; Mitchell et al., 1997; Walker et al., 2008): (1) Power—is the stakeholders' power to influence the issue at stake or study objectives significant or relatively limited? (2) Proximity/Legitimacy—are they directly impacted by the consequences of action or inaction on the issue at stake or the research problem identified? (3) Urgency—what is their stake? Are they prepared to go to any lengths to address the issue at stake with or without other stakeholders? The stakeholders are then rated on each of these three factors on a subjective but relative ordinal scale of 1 – 5 (Walker et al., 2008). The stakeholders can then be clustered into primary and secondary stakeholders (Campbell, 2004) or categorized using different typologies (Mitchell et al., 1997).

Stakeholder Mapping (Visualization) - The data from the first two steps are converted into the Stakeholder Map. The relationships that visualization shows will reflect stakeholders' unique relationships (Walker et al., 2008). Various techniques for mapping of stakeholders exist. The most commonly used methods for analysis or mapping of stakeholders plot the stakeholders on a matrix/grid which has two key attributes of stakeholders as its axes (Mathur, Price, Austin, & Moobela, 2007). There are also some more complex techniques for mapping the stakeholders which include the three-dimensional power/legitimacy/urgency criteria used at the prioritization stage (Mathur et al., 2007; Mitchell et al., 1997).

Stakeholder Engagement – This is the step stakeholders are engaged in the issue at stake (Walker et al., 2008). Defining appropriate elicitation protocol requires an understanding of each stakeholder's degree of influence or how they will be impacted by the actions and inactions on the issue under consideration.

Although many examples of stakeholder analysis with a policy orientation exist in the literature, none has been conducted on the agrifood nanotechnology industry. Inclusion of stakeholders in all aspects of the nanotechnology debate has been mentioned in many publications but none actually demonstrate a concrete methodology for performing a stakeholder analysis on nanotechnology experts (Davis, 2007).

Stakeholders in the agrifood system are wide ranging depending on the issue of concern.

Expert Elicitation

The use of expert elicitation has not been without controversy. However, it has been used as a very important research tool in policy analysis and several studies have justified and addressed issues of trustworthiness with its use. The term "expert" has not been defined using any quantitative measure but has been used to describe any individual or group of persons whose current or past fields are in the area of study, and who is/are seen as being more knowledgeable about the subject (Cooke & Goossens, 2004). Expert identification for a particular subject implies getting individuals or persons whose area of work or practice is in that particular subject area and whom others regard as knowledgeable. Although expert knowledge is not a certainty it has always played a large role in science, technology and engineering and it is used within certain level of confidence, acceptability or degree of belief (Van der Fels-Klerx, Goossens, Saatkamp, & Horst, 2002). There is a broad acceptability of expert judgment as just another type of scientific data, and methods are increasingly being developed for treating it as such (Goossens, Cooke, Hale, & Rodić-Wiersma, 2008).

Expert opinion is regularly sought when technical uncertainty or ambiguity impacts on a decision process; and soliciting expert advice in such cases is not new (Aspinall, 2008). Historically, it has been approached on an informal basis, and it has never been found entirely satisfying or immune to legitimate criticism, by all stakeholders (Aspinall, 2008). To avoid these shortcomings, a well-designed expert judgment elicitation is designed to treat expert opinions as scientific data in a formal decision process by subjecting the whole process to transparent methodological rules (Aspinall, 2008; USEPA, 2009).

The simplest and the most preferred method in the absence of a better alternative, is to take all expect scores to have equal weight (Cooke & Goossens, 1999). Although this approach has an obvious appeal, it has its problems. An expert with a very strong divergent opinion from the other experts can have a huge impact on the resulting conclusion. This becomes a critical issue if this expert's assessments cannot be properly explained (Hoffmann, Fischbeck, Krupnick, & Mcwilliams, 2006). However, as more and more experts are brought into the study, the weight of the score of an individual expert tends to become quite diffuse. Another problem associated with expert elicitation is the systematic overconfidence exhibited by both experts and non-experts (Morgan, Pitelka, & Shevliakova, 2001) "That is, given their knowledge; their subjective probability distributions tend to be too narrow" (Morgan et al., 2001, p. 282).

After the set of experts has been identified as part of the process, a decision is made as to which experts to use in the study depending on the criteria outlined for the study. In most studies, the largest number of experts is chosen based on the level and availability of resources (Cooke & Goossens, 1999). Experts used in some previous notable studies have been within the range of 5 – 20 (Linkov et al., 2006; Morgan & Henrion, 1990). According to Goossens, Jones, Ehrhardt, Kraan, and Cooke, (2001) "a panel of eight experts is to be recommended as a rule of thumb; and in any event, at least four experts for a given subject should be chosen" (p.159).

The use of experts' names and how to manage the identity of experts are also recurring issues in the literature. The general consensus however, is that expert names and affiliations should be part of the published report but individual experts should not be associated by name with their assessments (Cooke & Probst, 2006; USEPA, 2009). Based on several different reasons, the association should be preserved as part of the scientific record, and be opened to competent peer review, but not to be made public. Goossens et al., (2001) and also in their contribution to a USEPA Taskforce document on expert elicitation gave the following reasons (USEPA, 2009):

- That experts working in a particular company or firm may participate in the elicitation process as a condition of a client and may have different opinions which may be against the “company position;”
- experts should be shielded from “expert shopping” by litigants in a lawsuit who may seek experts whose opinions may support their positions;
- experts do not want to be subpoenaed or otherwise cross examined as a consequence of the open and sincere articulation of their views; and
- experts should be protected from insidious comments regarding their performance.

Strategic Flexibility Framework

The Strategic Flexibility Framework (SFF) is a scenario analysis tool and its use in this study is based on the idea that Educators and Human Resource Development professionals require flexibility to adjust decisions within given constraints. Various definitions of ‘scenarios’ can be found in the literature. Bradfield, Wright, Burt, Cairns, & Van Der Heijden, (2005) have contended that “there appears to be virtually no area in scenarios on which there is wide-spread consensus; the literature reveals a large number of different and at times conflicting definitions, characteristics, principles and methodological ideas about scenarios" (p.796).

There is however, a broad agreement that all the definitions converge, in that, scenarios are not forecasts or predictions of future developments, but rather descriptions of how the future might unfold, mapping out the 'possibility space' of future developments (Bradfield et al., 2005; Giaoutzi, Stratigea, Leeuwen, & Nijkamp, 2011; Zanoli, Gambelli, & Vairo, 2012). Zanoli et al., (2012) defined scenario analysis as a tool for strategic policy analysis that allows researchers and policymakers to support decision making, and a systemic analysis of the main determinants of an organization, sector or policy issue. Scenario analyses are powerful tools in modern policy analysis, in both the private and the public domains (Giaoutzi et al., 2011).

Scenario analyses are very different from other forecasting methods in that they usually provide a more qualitative and contextual description of how the present will evolve into the future, rather than a description that seeks numerical precision (Bradfield, 2008; Zanoli et al., 2012). Another important difference is that, they are generally used to identify a set of possible futures, where there is the possibility of occurrence, but without any certainty (Zanoli et al., 2012). Therefore, one will have to understand that "scenario analysis is a process of understanding, analyzing and describing the behaviors of complex systems in a consistent and, as far as possible, complete way". (Zanoli et al., 2012, p.42). Wack, (1985) defined scenario analysis as: "a discipline for rediscovering the original entrepreneurial power of creative foresight in context of accelerated change, greater complexity and genuine uncertainty" (p. 150).

Although scenario techniques have a long history dating back in time immemorial, the modern day scenario techniques, only emerged in the post-war period and was originally developed for strategic military purposes (Bradfield, 2008; Bradfield et al., 2005; Zanoli et al., 2012). From the work of Herman Kahn and others at RAND and the Hudson Institute in the 1960s, scenarios reached a new dimension with the work of Pierre Wack in Royal Dutch/Shell (Saritas & Nugroho, 2012). Since then numerous models have been published, with the first journal article on comprehensive model for the development of scenarios published by Zentner in 1975 (Bradfield, 2008). The literature is now replete with descriptions of prototypical patterns or models for generating scenarios ranging from the simple to the elaborate and highly structured recipe-type techniques (Bradfield, 2008).

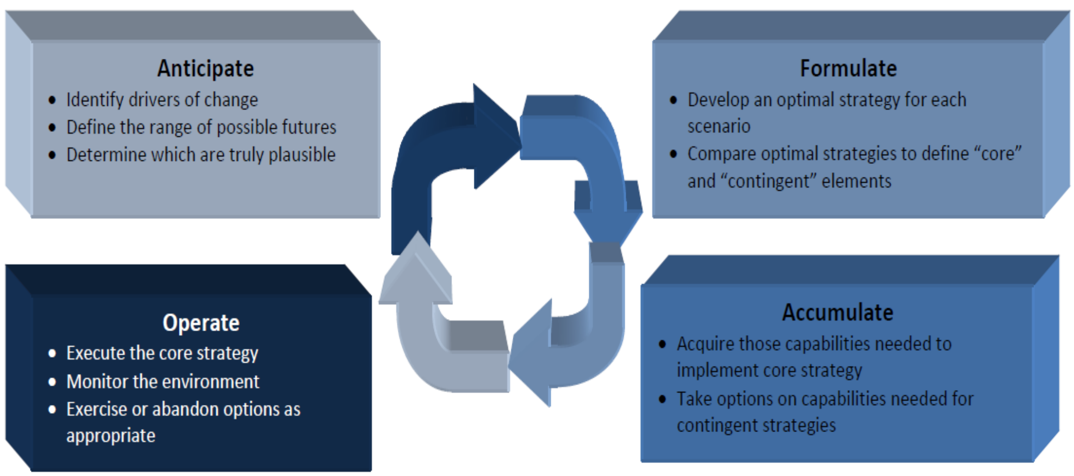
Scenarios can be categorized into exploratory/forecasting and normative/inward/ backcasting. Exploratory scenarios begin with the analysis of the present and link to the future by asking questions such as “What next?” and “What if?” (Saritas & Nugroho, 2012; Zanoli et al., 2012). Normative, or inward scenarios, involve backcasting, where the focus is not on what futures are likely to happen, but starting with the most desirable future (Giaoutzi et al., 2011). Typical questions for normative scenarios are “Where to?” and How to?”(Saritas & Nugroho, 2012). Scenario analysis can also be classified into quantitative and qualitative scenarios. While quantitative scenarios are often model based, qualitative scenarios describe possible futures in the form of narrative texts or ‘‘story lines’’(Zanoli et al., 2012). Another important classification of scenarios based on the approach used is categorized into participatory/expert-based scenarios, and desk-analysis scenarios. Participatory scenarios are approaches where experts and stakeholders play active roles in the scenario-generation system (Zanoli et al., 2012). Desk analysis scenarios exploit information based on the existing literature and/or statistical data, which is then elaborated in a scenario form without a collaborative process (Zanoli et al., 2012).

The basic aim of scenario analysis is not forecasting the future, or fully characterizing its uncertainty, but rather bounding this uncertainty (Zanoli et al., 2012). Scenario analyses help focus attention to driving forces, possibilities of evolution, and the extent of contingencies that may be confronted (Saritas & Nugroho, 2012). They are particularly useful when many factors need to be considered, and the degree of uncertainty about the future is high (Saritas & Nugroho, 2012). “With respect to nanotechnology, scenario planning may serve as a useful technique for scientists and engineers to engage with social scientists, humanists and policymakers in better understanding and reflecting about nanotechnology in society” (Farber & Lakhtakia, 2009, p. S5).

Strategic uncertainty that is associated with identification of future skill needs for emerging agrifood nanotechnology requires strategic flexibility, the ability to change strategies (Malik, Yawson, & Hensel, 2009a-b). Agricultural educators and human resource development professionals in the agrifood system risk arbitrarily narrowing their options of meeting the challenge of developing the human resources equipped with the requisite agrifood nanoskills if they attempt to base how the workforce should be developed on a precisely predicted skill requirements alone. This could prevent the consideration of a broader range of future possibilities. Agricultural educators and human resource development professionals need a range of future possibilities and corresponding strategy choices in tailoring their activities, rather than one strategy based on a declared vision of certain future skill requirements (Malik, et al., 2009a-b). The 'known unknowns' are also very important.

As shown in Figure 2, SFA is a four-step framework, defined by Michael Raynor in his book *The Strategy Paradox*: *Why Committing to Success Leads to Failure (and what to do about it)*. The implementation steps are Anticipation, Accumulation, Formulation, and Operation. Figure 2 is a pictorial representation of the framework adapted from Raynor (2007). The following description of the steps is drawn heavily from Malik, Yawson and Hensel's (2009) *focus on the future of food* report.

Figure 2. *The four phases of strategic flexibility*



Note: Re-drawn from Raynor (2007)

Anticipate – The process begins by defining the drivers that are shaping the agrifood nanoskill needs of the future. Once these drivers are understood, the next step is to develop scenarios that provide "stories" about possible future realities (Malik, et al., 2009). These scenarios are statements of how the nanotechnology could shape the entire agrifood system and the logical consequence for new skills requirements.

Formulate - For any given scenario, this step determines the strategies for success under different conditions. Each scenario has an optimal strategy. Each optimal strategy consists of various constituent elements — technologies, capabilities, and assets — required to execute the strategy. Elements common to many optimal strategies (one derived from each scenario) are core elements; those common to a few or one optimal strategy are called contingent elements.

Accumulate - Core elements have little strategic risk because they are part of the optimal strategies for multiple scenarios. Contingent elements require an options-based approach, which gives choices for allocating resources. In the accumulation phase, the decision maker commits to core elements and takes options on contingent elements.

Operate - This step involves monitoring the environment to determine which scenario accurately captures the most important elements of the future. This involves choosing the most appropriate optimal strategy, determining the necessary contingent elements, and deciding which options to exercise or abandon. The set of scenarios must be reviewed and, if needed, refreshed, or redeveloped.

Systems Dynamics

System dynamics as a discipline uses systemic feedback mechanisms to deal with dynamic policy problems (Barlas 2008). Such problems arise from the interactions between the different variables that characterize the system and from the feedbacks between the decision-making actions and the corresponding system's reactions. The main goal of a system dynamics study is to identify a dynamic problem and to understand the causes of the problem, and then search for policies that alleviate or eliminate those problems (Barlas 2008). System dynamics modeling is a tool that can account for complex and dynamic features of systems.

The agrifood sector extends from input supply industries and agriculture to food processing, food distribution, and retail (Porter 1998). The impact of nanotechnology throughout the sequence of different stages of sourcing, production, processing, and distribution involved in the provision of food to consumers; and the interrelationships between the actors and the skill and educational requirements needed for the actors in the value chain constitute a classical ‘‘System Dynamics’’ environment, which is characterized by processes that incorporate feedback loops as well as sequences of causes and effects with possible time delays in between (Fritz & Schiefer 2008a). This dynamics become even more interrelated when one considers the multidisciplinary nature of nanotechnology and its applications in the agrifood system and how to develop the appropriate workforce.

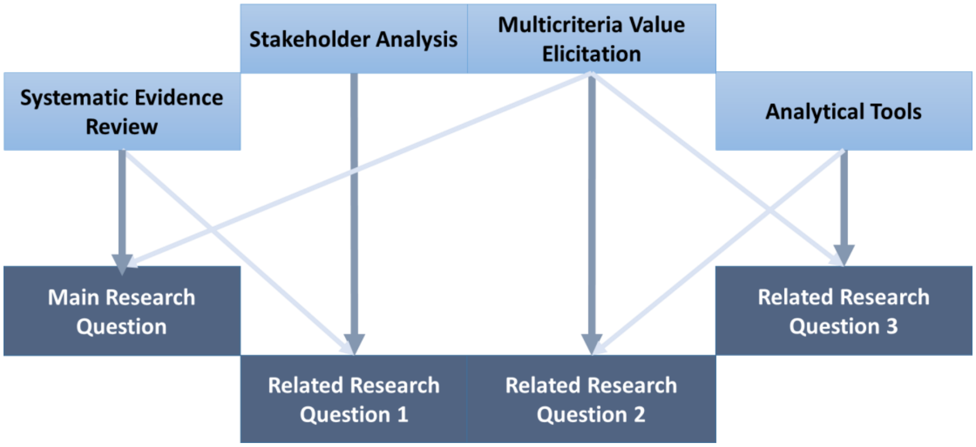
Chapter 3 – Methods and Methodology

This chapter presents the different methods and approaches used in collecting data for this study. The methods and data collection measures were designed to answer the research questions the study set out to address. The main research question guiding this study is: ***What are the future skill needs in agrifood nanotechnology?*** The study also addressed the following related questions:

1. Who are the key stakeholders in agrifood nanotechnology workforce development and how do they perceive skills shortages and gaps in the sector?
2. Based on an understanding of skill shortages and gaps, how can educational practice and policy meet these needs?
3. What policies and programmatic intervention points can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector?

The research methodology designed to answer these questions is as follows: First, a systematic evidence review of the literature was done to answer the main research question. A stakeholder analysis was conducted to identify the stakeholders directly affected and responsible for skill needs in agrifood nanotechnology and also to select the stakeholders from whom data will be collected. A Multicriteria Value Elicitation of quantitative and qualitative evidence was then collected from the identified experts and stakeholders. Figure 3 shows the main methods used to answer specific questions.

Figure 3. *Main methods answering specific research questions*



Systematic Evidence Review of Literature

The overall approach to the systematic evidence review for this study was adapted from the guidelines in the Cochrane Handbook for Systematic Reviews (Higgins & Green, 2011) and guidelines for systematic reviews in the social sciences (Petticrew & Roberts, 2006). Answering the research question on 'what are the future skill shortages and gaps in agrifood nanotechnology' involved synthesizing quantitative and qualitative evidence (Harden & Thomas, 2010). The following steps were followed: search for materials, screen studies, extract data, summarize data, perform analyses, and write up results (CRD 2009; Dixon-Woods, Agarwal, Jones, Young & Sutton, 2005; Pope, Mays, Popay, 2007; Thomas & Harden, 2008).

Search for Materials

For the initial search for materials, literature synthesis was done using text mining [process of analyzing text to extract information that is useful for particular purposes (Witten, 2004, p.137)] to extract technical intelligence [The ability to act on technical information flexibly to understand means–end relations and specific subject affordances, pertinent to the study of interest and complemented by suitable tacit knowledge of the researcher (Porter, Schoeneck, Frey, Hicks, & Libaers, 2007)] on ‘skill needs identification’ from the global AgEd, HRD, and nanotechnology research literatures. An extensive ‘skill needs identification’ query was applied to the ISI Web of Knowledge/Science Citation Index/Social Science Citation Index/Arts & Humanities Citation Index (ISI-SCI/SSCI/A&HCI) databases. The following terms and phrases were used in the search for materials: nanotechnology competencies/ nanotechnology expertise/ nanotechnology skills/ nanotechnology qualifications/ nanotechnology skill needs/ nanotechnology skill identification/ nanotechnology skill gap/ nanotechnology skill shortage/ nanotechnology future skill needs/ nanotechnology skill requirements/ nanotechnology workforce needs assessment/ nanotechnology workforce education/ nanotechnology workforce development/ nanotechnology education/ nanotechnology curriculum. Each of these terms and phrases were searched independently and in combination with the terms agriculture/food/agrifood. The key terms were also searched in combination.

In addition to the citation indexes, I also queried an expansive search covering several disparate electronic databases including, AGRICOLA, Business Source Premier, EconLit, Academic Search Premier, Google Scholar, Education Full Text, and ERIC. Cross-referencing and searching of the references of some key articles occurred to obtain lists for other related studies. In addition to this, handsearching of several of the key journals in the field of HRD, AgEd and Nanotechnology was conducted.

Handsearching involves scanning the content of journals, using the journal’s own search tool. Finally Google Scholar alerts were set up for each of the key terms and phrases in combination with Nanotechnology and this provided real-time information on any developments, news item, and publication relevant to the study throughout the study period. Overall a total of ***5013*** articles were downloaded

Prioritization & Selection of literature (Screen studies)

For the prioritization of materials, the initial searches of all materials were uploaded into Mendeley Citation Software and screened in terms of their relevance to research question using abstract reviews and this resulted in ***1088*** most pertinent articles. In order to simplify the evidence collection process, each identified source was evaluated using explicit criteria, to include and exclude studies. These criteria were adapted from Yawson & Kuzma (2010), Pope et al. (2007) and CRD's guidance for undertaking reviews, and included:

- the quality of the source – peer-review journal publication, edited conference proceedings, report from recognized research centers and universities;
- the approach to the primary research and the methodology used; study specificity of how the study is situated within HRD/AgEd/Public Policy – agrifood nanotechnology literature or studies which are not related to skill needs or workforce development in general were excluded;
- the level to which the source discussed the broader research question on 'what are the future skill needs in agrifood nanotechnology?'

This resulted in a total of ***84*** articles.

Extraction, Summarization and Analyses of Data

The ***84*** selected articles were exported to an *EPPI-Reviewer 4.0*: software for research synthesis (Thomas, Brunton, & Graziosi, 2011). The articles were either imported directly from the search engine or first saved in Refworks/Zotero before exporting to EPPI-Reviewer which was used to help import data on articles and other publications into a database for easy access and manipulation. Other data including the most cited papers, authors with most papers, and location of authors were also obtained using the software. This information helped with the expert identification. Using the following key phrases: Agrifood; Agriculture; Food; farmers; workforce; Education; and human resource development, 53 articles were selected for the evidence review. The overall presentation of the results of the systematic review followed the approach used by Gaugler (2010). Gaugler, (2010) stratified the research evidence into three broad categories: (1) cross- sectional studies (2) longitudinal studies, and (3) qualitative studies that identified themes pertaining to the study question. The results were tabulated for each of these three study types. In this study research evidence was also stratified into three categories: Empirical evidence, review /conceptual evidence, case study evidence of studies on skill needs identification.

Stakeholder and Expert Identification Analysis

The second task of the first phase of the study entailed stakeholder and expert identification analysis. From the SER some experts were identified purely based on their publications in peer-reviewed academic journals. Other source of Identification included nanotechnology conferences participants list. Overall 258 nanotechnology experts were identified with activities related to agriculture. The survey was sent to them electronically using Survey Monkey Software. The study followed a 4-step process of

Specification, Prioritization, Mapping (Visualization) and Engagement for the stakeholder analysis.

Stakeholder Specification

This is the stage where stakeholders were defined and identified in relation to workforce development for the agrifood sector. The study adapted the stakeholder analysis approach developed by Varvasovszky and Brugha, (2000) for the stakeholder specification. Stakeholder specification provided a basic understanding of the social and institutional context in which this study was conducted. This task developed a framework of the agrifood nanotechnology network of stakeholders. This structural approach also supported the subsequent assessment of the agriculture and food stakeholders in regard to their perception of nanoskill needs.

At a general level I separated the stakeholder universe into multiple units of analysis based on Yawson's, (2012) ‘Nanoliteracy Quintuple Helix Construct’: the public component (stakeholders who see and approach agrifood nanotechnology as scientific inquiry which will ultimately impact everyone), the business [industry] component (stakeholders who approach agrifood nanotechnology as investment/ entrepreneurial opportunity/farm business), the academic component (stakeholders who approach nanotechnology with human capital development mission), the Third Sector component (stakeholders who advocate for the use and non-use of nanotechnology), and the government [regulatory/ federal] component (stakeholders responsible for economic, ethical, legal, and social, policy). Figure 4 is a diagrammatic representation of this multiple unit of analysis and Table 3 shows the typology used in prioritizing the stakeholders.

Figure 4. *Agrifood Nanotechnology Stakeholder Unit of Analysis*

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The main questions that guided the identification of stakeholders are: Who, in general, are the main stakeholders in the agrifood nanotechnology workforce development network, what are their particular areas of interest, and how they are defining skill requirements for agrifood nanotechnology? Using Varvasovszky and Brugha's (2000) stakeholder analysis matrix and Yawson's, (2012) Nanoliteracy Quintuple Helix Construct, a stakeholder map was constructed. The boundary of each stakeholder cluster was defined, as discussed under the next section on stakeholder specification, and the stakeholders were identified based on the literature.

Table 3. *Framework for Stakeholder Analysis of Agrifood Nanotechnology Skill Needs*

Stakeholders	Power	Proximity/Legitimacy	Urgency	Representatives identified for the study (sampling)
Government				
Industry				
Academia				
Public				
Third Sector (NGO's)				

Academia in this stakeholder analysis is not referring to only higher education but as Yawson, (2012) described, it encompasses all levels and forms of education. The constituent stakeholders in the academia unit of analysis were categorized as follows: Institutions offering bachelor degree programs; institutions offering master degree programs; institutions offering doctoral degree programs; institutions offering doctoral TVET/CTE programs; institutions with nanotechnology workforce development programs and infrastructure; institutions with infrastructure and programs for K-12 nanotechnology education; and professional and academic bodies of interest.

As stated earlier government as unit of analysis for the stakeholder study was defined as the regulatory/ federal component of stakeholders responsible for economic, ethical, legal, and social, policy with the goal of making agrifood nanotechnology education policy more rigorous, transparent and scalable. A government entity is any organization that is funded by the government and formed to fulfill the policy of the government in a given area. The constituent stakeholders in the government unit of analysis were categorized into Government laboratories and Centers; and Government Agencies for this study.

The ‘third sector’ is a collective term for all those organizations that are not-for-profit and non-government, in addition to activities of volunteering and giving which sustain them (Australia and New Zealand Third Sector Research (ANZTSR), 2012). Although there are vast differences among them, third sector organizations are completely different as a group from government and private (industrial) organizations (ANZTSR, 2012). They are characteristically mission driven and have a tendency to value consensus decision making. In this analysis the third sector stakeholders were advocacy groups and other non-governmental and not for profit organizations directly interested (for or against) the use of nanotechnology in food and agriculture. Industry as a unit of analysis includes all stakeholders in the agrifood nanotechnology sector involved in the agribusiness food chain from farm to fork.

Stakeholder Prioritization

Time, scope of the project, finances and other resources available to this study were the main reasons for this stage of the SA approach. Since these resources are limited, the list of stakeholders to be interviewed were prioritized (Schmeer, 1999). The stakeholder prioritization was undertaken by considering three factors that assessed the relative importance of stakeholders (Elias, Cavana, & Jackson, 2002; Mitchell et al., 1997; Walker et al., 2008). Using the following typology to prioritize them on a scale of 1 (lowest) to 5 (highest) experts were surveyed: (1) Power—is the stakeholders' power to influence skill development in agrifood nanotechnology significant or relatively limited? (2) Proximity/Legitimacy—is the stakeholder directly impacted by the consequences of action or inaction on the issue at stake i.e. skill needs for agrifood nanotechnology? (3) Urgency—what is their stake? Is the stakeholder prepared to go to any lengths to address the issue at stake with or without other stakeholders? The stakeholders were then rated on each of these three factors on a subjective but relative ordinal scale of 1 – 5 (Walker et al., 2008) by the experts.

Stakeholder Mapping (Visualization)

The data from the first two steps are converted into the Stakeholder Map. The relationships that visualization shows will reflect stakeholders' unique relationships (Walker et al., 2008). See Figure 9 under the results section.

Stakeholder Engagement

This is the step stakeholders were engaged in the issue at stake (Walker et al., 2008). Various stakeholder groups were surveyed. Defining appropriate elicitation protocol requires an understanding of each stakeholder's degree of influence or how they will be impacted by the actions and inactions on the issue under consideration. Please see Appendix B for the various survey instruments.

Multi-Criteria Value Elicitation from Key Stakeholders and Experts

There are a number of methods for stakeholder and expert value elicitation available. The actual methods that were employed in this study relied on a combination of different value elicitation processes. A methodology for the expert elicitation was developed based on Van der Fels-Klerx et al., (2002) and Yawson & Kuzma, (2010)'s work using formal survey methods. The methodology involved both qualitative and quantitative elicitation. A four-step process: selection of stakeholders (study participants) including experts as described above, development of the elicitation survey instrument, administration of the elicitation survey, and analysis of the survey results was done (please see next chapter for the analysis of the results). The elicitation protocol developed for this study took into account the level of heterogeneity of relevant backgrounds seen in the disparate disciplines involved in agrifood nanotechnology (Yawson & Kuzma, 2010). Interviews to elicit experts' opinions were conducted by telephone following traditional social science interview methodologies (e.g. Berg, 2009; George & Bennett, 2005). Interviews were recorded (with permission and following Institutional Review Board requirements) and transcribed for analysis.

In this study, key stakeholders and experts were queried through surveys to elicit response on ‘skills that are needed and will be needed’ for the emerging agrifood nanotechnology sector. The key assumption here was that understanding stakeholder values may allow experts to characterize individual preferences for new alternatives, enabling agricultural educators to develop the most acceptable curriculum and educational requirements for the agrifood nanotechnology human resources pipeline.

In summary the method followed the following steps:

- Systematic evidence review of the literature to answer the main research question, stakeholder specification and expert identification, and preparation of survey instruments
- Stakeholder prioritization through the survey of experts; and concurrent survey of experts on key issues identified through the SER
- Survey of key stakeholders
- Interviews of experts on the key outcomes of the stakeholder surveys.

Sample

The study used mixed methods sampling strategy combining the concurrent and sequential collection of quantitative and qualitative data (Creswell & Plano-Clark, 2010; Teddlie & Yu, 2007). The sample sizes of stakeholders and experts surveyed and interviewed varied. Overall a total of 225 participants, including individuals (experts and individual stakeholders) and representatives of stakeholder groups: Educational institutions, industry/business, and government organizations responded to the various elicitation protocols. Because different communities of stakeholders were surveyed and several of identified stakeholders in the agrifood system who were ready to discuss nanotechnology skill needs were small, the interest in the sampling was more to do with the representation of the stakeholders rather than actual sample sizes. As a result the quantitative data analysis was limited to descriptive statistics.

Data Collection/Measures

This multiphase mixed method design combined both sequential and concurrent strands within a particular timeframe (Creswell & Plano Clark, 2011). The first phase of the data collection involved both qualitative and quantitative data which were collected through online surveys. Experts were first surveyed as part of the stakeholder analysis and then quantitative and qualitative data were collected from both experts and stakeholders and analyzed. The quantitative data included structured questions on ranking and Likert scales to augment the data obtained from the systematic review in answering the main research question. These quantitative questions were developed for the purposes of this study from evidence obtained from the systematic review of literature in answering the question: What are the future skill needs in agrifood nanotechnology? The validity and reliability of these questions were addressed through evidence from the systematic reviews and an input from an expert, although there were no psychometric analysis of these questions (as many items were single queries, and the small sample sizes of the various stakeholder groups limited formal testing of reliability and measurement validity). The questionnaire that was developed went through a number of development stages before it was finalized. The face validity was tested using comments from colleagues on social media. The qualitative data involved semi-structured questions to elicit opinions on key issues that came from the systematic review, such as: 'What do you see as the major skill needs in agrifood nanotechnology sector?'

The semi-structured questions were made specific to each expert stakeholder unit. Using evidence from the systematic review, questions were formulated to elicit responses to address the first related research question on how experts and stakeholders in agrifood nanotechnology perceive skills shortages and gaps. Basis for the classification of employability and technical skills are several comprehensive sector studies that were used to identify emerging skills needs and a number of surveys in the field of skills, (CEFIC, 2011; Freikamp & Schumann, 2007; Gelderblom et al., 2012; Lindner, Dooley, & Wingenbach, 2003; Robinson & Garton, 2008; Singh & Dunn, 2007). The technical skills are based on the International Standard Classification of Education (ISCED) as used in Gelderblom et al., (2012)

The second phase of data collection involved additional qualitative data. Results of the stakeholder surveys were discussed with the experts through qualitative phone interviews (two local experts were interviewed in person). These semi-structured telephone interviews discussed key issues from phase one of the data collection to elicit opinions of experts on important systems variables that were identified from both the systematic review and the first level data collection to help answer the 3rd and 4th research questions. Overall 14 experts were interviewed. Table 4 gives the details of the experts that were interviewed including nine experts from academia, four from industry/business and one from government.

Table 4. *Stakeholder Unit and Affiliations of Experts Interviewed*

#	Stakeholder Unit	Qualification	Affiliation & Position
1	Academia	PhD	Professor of Nanobiotechnology and Agribusiness
2	Academia	PhD	Technical Director, University based nanotechnology research center
3	Academia	PhD	Professor of Agrifood Nanotechnology
4	Academia	PhD	Professor of Nanotechnology and Workforce Education
5	Academia	PhD	Professor and Director of University-Based Nanotechnology Research Center
6	Academia	MS	Professor and Director of Nanotechnology Program at a Technical/ Community College
7	Academia	PhD	Director of University-Based Nanotechnology Research Laboratory
8	Academia	PhD	Professor and Dean of Nanotechnology Program at an RI University
9	Academia	PhD	Professor & Chair of Department of Nanotechnology at an R1 University
10	Government	PhD	Technical Director of a government Laboratory
11	Industry	PhD	Nanotechnology Business Consultant
12	Industry	PhD	CEO, Agrifood Nanotechnology Start-up
13	Industry	PhD	Technical Director of Industrial (AgriTrade) Association
14	Industry	PhD/JD	Assistant VP of HR, Large Scale Agrifood Company

Chapter 4 – Results

This chapter presents all the results from the different phases of the study. The results of the systematic evidence review, stakeholder analysis, and the multicriteria value elicitation of experts' and stakeholders' opinion are reported.

Results of the Systematic Evidence Review

The overall presentation of the results of the systematic review followed the approach used by Gaugler (2010). Gaugler, (2010) stratified the research evidence into three broad categories as described in the methods section of this dissertation. In this study research evidence was also stratified into three categories: Empirical evidence; review /conceptual evidence; and case study evidence, of studies on skill needs for agrifood nanotechnology. Further categorization was done based on the focus of the research in relation to the major themes of this study and specifically the relation to the main research question. Skill Needs/Gaps/Shortages; Educational Requirements/ Curriculum Developments; Workforce Developments; and Policy Interventions. The country or region where the study was situated is also indicated. The results are shown in Table 5.

Table 5. *Tabulated Results of Systematic Evidence Review*

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Abicht, Freikamp, & Schumann, 2006	EU	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments Skill Needs/ Gaps/Shortage	• Specific knowledge and qualifications are needed particularly for the production of nanotechnology products and the control of nanotechnology production methods. • At this stage of development only first attempts can be defined regarding the medium-term demand for personnel with intermediate-level qualifications. • The current scope of research activities in nanotechnology is the reason for the high demand for personnel with primarily university degrees. The demand for staff with qualifications below university level is comparatively low at present. Nevertheless, the study records a number of cases of lack of qualified staff below university level. Because of a high degree of automation, such work activities as process control, quality assurance and documentation will increasingly be assigned to qualified employees with a qualification below university level. • New fields of activity occur in the area of marketing and sales. • Employees with qualifications below university level need particular interdisciplinary knowledge and strong social competences to take part in cooperation and innovation processes in the enterprises. • With the increasing demand for employees with qualifications below university level (number of people) as well as with the increasing need for integration of new knowledge components, it can be expected that enrichment of existing qualification by additional knowledge and skills (courses) does not qualitatively satisfy enterprises any more. • International comparison reveals extensive public promotion of natural sciences and technology research, but few activities to identify and develop necessary human resources. As far as these activities are promoted, they are usually a component of scientific or technological research and lead to individual solutions without involving neighboring areas in a systematic manner. This can cause a shortage of qualified personnel in the medium term. • A significant proportion of public funds (e.g. 5 %) should be used to identify skill needs and to develop and test training to prevent obstacles to the economic utilization of research results through a shortage of human resources. Individual solutions are to be augmented by a systemic approach both for initial education and for further training.
ANGLE Technology Group, 2004	US	Empirical	Policy Analysis	• Continuing support for nanotechnology technician training as a foundation for multiple careers utilizing nanotechnology, • Developing further K-12 outreach programs aimed at introducing nanotechnology concepts and basic principles to students at an early stage. • Explicitly incorporating nanotechnology into the STEM curriculum. • Emphasizing the role of Community Colleges in training and retraining and tailoring programs to industry needs. • Supporting and promoting industry internships and co-ops with participating universities and key industry players targeting Nanotechnology to provide more industry-focused training for specific vertical markets. • Support pursuit of NSF education and training initiatives including new Nanotechnology Learning Centers.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Barakat & Jiao, 2011	US	Case study	Educational Requirements/ Curriculum Developments; Workforce Developments	• Demand has risen significantly for a workforce capable of supporting Nanotechnology. • This workforce is required in the trenches of nanotechnology implementation more than in the R&D level. • This, in turn, increases requirements for the fast development and implementation of specific courses and curricula at the undergraduate level to help produce this much needed workforce. • Challenges related to introducing nanotechnology into undergraduate education will continue to exist
Brooks et al., 2008	US	Empirical	Skill Needs/ Gaps/Shortage; Workforce Developments	• Although satisfied with the level of technical knowledge provided in the current college curriculum, employers were less pleased with the professional skills demonstrated by their college-educated workers, noting particular shortcomings in the levels of team building, initiative, leadership, and communication skills. • From the results, it is evident that one of the challenges that must be faced in the agribusiness labor market is how to bridge the gap between the skills needed by agribusiness employers and the curriculum content of major agribusiness-related degree programs. • The labor market shortages suggested by the previous analyses must be reviewed in light of the skills shortages suggested by the survey responses
Burke, Jean, Brown, Barrett, & Leopold, 2009	US	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage;	• A nanotechnology workforce that is science-grounded and skill-based is needed to ensure a flexible workforce. • A generalist approach to nanotechnician training is required. Which instills multidisciplinary KSA's that easily cross disciplines. • The very nature of the nanoscience field demands a broad educational foundation in physics, biology, chemistry, mathematics, process flow and control, quality assurance and control as well as societal and environmental issues • Predictions indicate that the world will experience a dramatic increase in the need for well-trained nanotechnologists. • Current numbers of training programs are insufficient at present levels to meet such a potential and future need. • If the predictions hold true, the workforce needs and the long-term success of industries utilizing nanotechnology in their manufacturing processes will only be helped by a consistent supply of uniformly well trained and educated employees who are generalists in terms of the nanotechnology background have a broad educational foundation and an interdisciplinary set of skills.
Burnett & Tyshenko, 2010	Canada	Empirical	Workforce Developments;	• The analysis shows human capital plays a role in the future prospects of both early nanotechnology investors (USA and Japan) and recent emerging markets (China and South Korea). • Knowledge and skills in the fields of science and engineering are crucial to the development of nanotechnology and deterioration in human capital can be a detriment to nanotechnology sector success. • Declines in human capital, as in the case of the USA, is suggested to greatly hamper • future success in the nanotechnology industry

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Chari, Irving, Howard, & Bowe, 2012	Ireland	Empirical	Workforce Developments;	• Nanotechnology research area may not progress as fast as it can if, the knowledge, skill and competences necessary to work in this complex area are not developed in the researchers working in this area presently or in near future. • Although funding agencies are supporting the N&N research area, they have also raised concerns about the shortages in the workforce in this area
Chen & Yada, 2011	US/ Canada	Review /conceptual	Skill Needs/ Gaps/Shortage;	• Education and workforce training are essential in enhancing scientific capabilities in all nations. • Young scientists should be trained to acquire new knowledge and skills required to be proficient workers and researchers in nanotechnology
Cibuzar et al., 2006	US	Case study	Educational Requirements/ Curriculum Developments; Workforce Developments;	• The projected growth in successful commercialization of nanoscience products and technologies will be slowed without an adequately trained force of technician-level skilled workers. • By most accounts, nanotechnology is a rapidly growing area of science and technology that will require large numbers of trained workers at all levels, from Ph.D. researchers • Nanotechnology needs workers with cross-disciplinary training to level not previously known, thus requiring new educational paradigms for educational and training programs.
Cleary, 2009	US	Empirical	Workforce Developments; Skill Needs/ Gaps/Shortage;	• Workers trained in traditional disciplines posses much of the core knowledge/skills needed to learn the basics of nanotechnology research on the job. • Workers need some understanding of core concepts including an understanding of the nanoscale (sub-atomic, atomic, molecular and supramolecular levels) and Quantum mechanics / quantum effects. • Key skill and knowledge requirements may vary from one industry to another. As a result, it is difficult for employers to identify specific “nanotechnology” skills and knowledge. • Employers value interdisciplinary skills for nanotechnology workers. • Nanotechnology-relevant skills/knowledge taught on the job • Chemical engineering and physical chemistry degrees preferred • Largest gaps in interdisciplinary knowledge - “breadth”, nanoscale properties & characterization, and ethics/ safety issues, biological effects (for chemists) • Lab techs need basic safety training • Very few workers need nanotechnology specific skills • BS-level chemical engineers need basic knowledge of nanoscale properties, characterization, and flow characteristics (for solutions processing) • Corporate managers/marketing/sales workers need basic knowledge of nanoscale and awareness of health & safety/ethical/legal issues.
DIIRD, 2008	Australia	Empirical	Workforce Developments; Skill Needs/ Gaps/Shortage;	• In common with many new and emerging technologies, there has been much speculation and hyperbole concerning the future of nanotechnology. This makes it difficult to predict the number of skilled workers and tertiary-trained graduates required to meet future demand

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Economic and Workforce Development, 2006	US	Empirical	Workforce Developments; Skill Needs/ Gaps/Shortage;	• Cultural differences between academic and industry workers as a significant impediment to any future nanotechnology industry development. • The skills audit found five broad areas of current and future activity that require different skills and capabilities • Interviewees also identified a set of competencies and attributes necessary for future workers in nanotechnology that are not featured in existing tertiary courses. • It is estimated that between 200 and 300 companies are using nanoscience or microscience in the Bay Area, and approximately 60% are either currently producing goods or expect to in the near future. • Because nanotechnology is an emerging science crossing many industries, estimating the level of employment is particularly difficult. • The data confirm there is a strategic opportunity for the community colleges in the region to partner with local industry to prepare the current and future labor force needed in the nanotechnology sector. • Gaps in workforce demand were found that indicate an opportunity to provide education and training to prepare students to fulfill the employment needs as technicians and manufacturing and production workers within firms using nanoscience. • There is also a need to upgrade current employee's skills to allow them to move up the career ladder within the converging biotechnology, information technology and nanotechnology sectors.
Falkner, Wiltse, Breen, & Robert Hummel, n.d.	US	Case Study	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage;	• Every aspect of workforce development will be influenced by the unique nature of nanotechnology. • Major changes in the scope and level of cooperation between the private and public sector will continue to be required. • The entire educational system will need to develop new models for a nanotechnology workforce - one that crosses all disciplines. This alone will require significant investment in teacher training and curriculum development. • There must be the recognition that levels of competitiveness in the nano field is global and so local, county and state policies must be adjusted accordingly. • The pace of development in the industry and global competition require broad based investment in human capital training. • The development of the nanotech industry in the region will have a major workforce impact on other industries requiring mid to high level skilled workers. • There is significant danger of a deficit in the workforce pipeline if there is not a sense of immediacy in addressing the human capital issues.
Fazarro & Trybula, 2011	US	Review /conceptual	Curriculum Developments; Workforce Developments;	• Lack of skilled and trained workforce in nanotechnology and nanosciences will be a problem in the coming decades, both the EU and US • Workers need to be trained in sustainable and safe manufacturing practices.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Feather & Aznar, 2010	US	Review /conceptual	Skill Needs/ Gaps/Shortage Educational Requirements/ Curriculum Developments; Workforce Developments;	• To have the greatest impact, safety training should be incorporated into two-year post-secondary and workforce education programs so that graduates enter the workforce with the knowledge, skills, and attitudes needed to maintain a safe workplace from the outset of their careers. • The needs of industry for high quality, well-educated scientists and engineers depend heavily on the larger education ecosystem. • To ensure a robust supply of workers, the entire ecosystem must be healthy, beginning with K–12 math and science education and continuing through various forms of postsecondary education. • Rather than a one-way path from K–12 to undergraduate to graduate school, society can be better served by interactions and partnerships among industry, academia, government, and the broader formal and informal education system.
Foley & Hersam, 2006	US	Review /conceptual	Educational Requirements/ Curriculum Developments;	• Unless fundamental changes are made in the educational infrastructure in the U.S. to reverse the general erosion of STEM education, and to address the specific growing need for a robust nanotechnology workforce, current trends in the global demographic of the high-technology talent pool and R&D infrastructure will lead to a shift in the global dominance in science, technology, and engineering from the U.S. to Asia. • For the U.S. to reverse these trends and thus maintain its technological and economic leadership, the infrastructure for nanotechnology education needs to be significantly enhanced. In particular, this infrastructure should include educational models and curricula that will institutionalize an interdisciplinary education, thus exposing students to the connections between disciplines and their relationship to nanotechnology at all levels. • While programs in nanotechnology are currently being developed for the K-16 level and the general public, significantly more effort is needed to develop effective and comprehensive nanotechnology education reform.
Fonash, 2001	US	Review /conceptual	Workforce Developments;	• Creating a properly prepared nanotechnology technician workforce, which is essential for manufacturing, is probably the most demanding educational task of all. • The implication of the ever-widening impact of nanotechnology is that the workforce must have a broad background encompassing an understanding of the principles of biology, physics, and chemistry as well as encompassing the engineering principles of design, process control, and yield.
Gatchair, 2011	US	Empirical	Workforce Developments;	• The U.S. faces several challenges in its efforts to educate individuals in S&E fields and to develop the S&E workforce, many of which will extend to the nanotechnology workforce. • The workforce needs of new nanotechnology industries may not be met. • The growth of nanotechnology will lead to the creation of some new jobs; however it is likely that the number of new jobs will not be as great as the numbers observed in older manufacturing industries. • Highly skilled individuals, in particular those with S&E backgrounds, will be favored, even for jobs that are not designated as S&E jobs.
Gelderblom et al., 2012	EU	Empirical	Skill Needs/ Gaps/Shortage	• Future shortages and skills gaps related to nanotechnologies are expected to increase. This refers mainly to high level graduates in the fields of Science and Technology (S&T). At the same time there is still quite a lot of uncertainty about future developments of demand and supply.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Horn & Fichtner, 2008	US	Empirical	Workforce Developments; Skill Needs/ Gaps/Shortage	• Besides various types of technical skills, personal skills such as creativity and ability to work in an interdisciplinary context are considered very important. • Companies are very critical about their cooperation with education institutes, while the perception of education institutes is that they are very active in this field. • In spite of developments like ageing and expected increasing skills gaps, lifelong learning in the sense of off the job training courses does not have a high priority for companies and higher education institutes. • The whole area of VET does not get much attention in relation to skills needs related to nanotechnologies. • Most companies that provided input for this study anticipated that they would increase their use of nanotechnology in the future. They could not be specific about their future workforce needs, however. • Researchers with advanced degrees in traditional disciplines possess much of the general knowledge and many of the skills necessary to learn the basics of nanotechnology research on the job • Employers consistently mention inter-disciplinary skills as an important skill for nanotechnology researchers, and an important skill deficiency. • While some employers are concerned about the supply of workers with necessary interdisciplinary skills, others believe that the shortage of skilled workers will be temporary as educational institutions adjust to industry need.
Horn, Cleary, & Fichtner, 2009	US	Empirical	Skill Needs/ Gaps/Shortage	• Pharmaceutical companies reported limited demand for nanotechnology workers in regulated and unregulated product divisions, and future hiring needs were unknown. • Employers interviewed preferred workers with traditional degrees and training them on the job. Skills gaps included interdisciplinary knowledge, especially at the intersection of biology and chemistry. • While the number of jobs affected by nanotechnology is small, nano- technology affects the knowledge and skill requirements of multiple job categories to varying degrees.
Horn, Cleary, Hebbar, & Fichtner, 2009	US	Empirical	Educational Requirements/ Curriculum Developments; Workforce Developments	• The total number of formal nanotechnology degree programs in the United States is small, with associate's degrees being the most prevalent, followed by doctoral degrees. • Nanotechnology degree programs are not concentrated in areas of high nanotechnology publication activity, but rather, clustered in response to federal and state investments. • Workforce and economic development are key motivators for the creation of associate's degree programs in nanotechnology, while reasons for creating other types of degrees are more diverse. • Employer involvement in degree programs is inconsistent. • A shortage of qualified faculty, limited consensus on learning needs, and other factors contribute to varied approaches to the interdisciplinary aspects of nanotechnology education in degree programs. • Partnerships among related programs were common, especially across institutions. • Little is known about the employment outcomes of nanotechnology degree program graduates. • Not surprisingly, the value of formal degree programs for meeting employer needs is unclear.
Invernizzi, 2011	US	Review /conceptual	Workforce Developments;	• Nanotechnology development and its progressive adoption by companies not only create new occupations but also demand new skills

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
James Murday, Hersam, Chang, Fonash, & Bell, 2011	US	Review /conceptual	Skill Needs/ Gaps/Shortage Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage	• As with any other new technology, nanotechnology will bring about substantial changes in the nature of labor, the skills required, the demand for labor force, and the allocation of workers in a reconfigured industrial structure. • Nanotechnology skills are based on an interdisciplinary science base • Nano-specific transversal skills are emerging • The so-called soft skills are valuable; • Adaptive training prevails. • Without incorporating the current understanding of nanoscale science and engineering into science and engineering learning standards in each of the states, action at the K–12 levels of education will be minimal, and increasing nanoscience literacy toward a productive workforce will be inadequate. • Many community colleges do not have the faculty, staff, and facilities resources to offer a meaningful nanotechnology education that includes exposure to state-of- the-art nanotechnology fabrication tools and, more importantly, to nanotechnology characterization tools. • The multidisciplinary/transdisciplinary nature of nanoscale science and engineering will continue to require center/institute type activity at colleges and universities. • A key infrastructure need is educators who are interested in, familiar with, knowledgeable about, and comfortable with teaching nanoscale science, engineering, and technology. • To compete effectively in world markets, it is now recognized there must be continued attention to NSE discoveries emanating from graduate education, motivated and skilled entrepreneurs who can transition discovery into innovative technologies, state-of- the-art equipment for fabrication and characterization, well-trained workers for the industrial communities, and well-informed, nanotechnology-literate citizens to sustain the workforce pipeline and public support.
JS Murday, 2009	US	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage	• Nanostructures can have new physical, chemical, and biological properties. This new knowledge should be incorporated into the educational corpus. • Nanoscale science and engineering is largely transdisciplinary. It challenges the traditional science and engineering education taxonomies. • The nanoscale holds sufficient novelty to attract STEM interest in students. • As nanostructures become materials building blocks and directed self-assembly becomes a viable manufacturing process, there will be a need for an informed, skilled workforce. • Workers and members of the general public may be in contact with nanomaterials in various forms during manufacture or in products and should be sufficiently knowledgeable to understand the benefits and risks. • The National Science Foundation (NSF) and other institutions' attention to education at the nanoscale (Nanoeducation) is developing and disseminating a wealth of new instructional materials, some of which are available as cyberinfrastructure resources.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Koehler & Koehler-Jones, 2006	US	Empirical	Educational Requirements/ Curriculum Developments; Workforce Developments	• Over all business sectors, 58% say they are currently able to hire technicians who are adequately trained for the job, but 39% say they are not. • The most important technical skills that applicants will need in the near future are: electronics, mechanical skills, and vocational skills such as welding, instrumentation, and basic shop. Familiarity with computer technology was ranked as being second most important. • With regard to personal skills, almost 40% said technicians of the future will need to understand basic employment issues. Some of the qualities mentioned include: attendance, work ethic, workmanship and productivity; desire to learn, self-motivation and self-direction; ability to follow directions and ability to work as a team. English language skill development is next in importance. • The evidence indicates that there will be a large demand for highly skilled technicians that the current workforce cannot fill.
Krieger & Appel, n.d.	US	Policy Analysis	Workforce Developments; Skill Needs/ Gaps/Shortage	• Desired Skill Sets for Mid-Level Technicians including the following skills set: Soft skills, Critical Thinking / Interpersonal Skills, & hard skills identified • Insufficient capacity in the training system to meet anticipated demands. • Employers see little value in the current workforce development system • Four-year college preparation is the education system’s primary mission • High schools do not do enough to prepare students for the world of work or college. • High schools do not connect with business, nor offer helpful career guidance. • The relationship between businesses and community colleges is of uncertain value to employers. • Successful pipelines already exist • At a time when there is a shortage of skilled workers, there are numerous populations that are underrepresented among mid-level technicians, including women and minorities
Malsch, 2008	EU	Review /conceptual	Educational Requirements/ Curriculum Developments; Skill Needs/ Gaps/Shortage	• In Europe, in 2004, 44% of 733 respondents to the “Open Consultation on the European Strategy for Nanotechnology” expected a shortage of trained staff in nanotechnology within five years, 24% in five to ten years and 3% after ten years. Only 8% believed such a shortage would never occur. • The respondents believed the lack of highly skilled staff to be the main difficulty for SMEs and start-ups in nanotechnology. • Almost half thought this was a crucial bottleneck, and about 30% thought it mattered “a lot”. Apart from nanotechnology knowledge, interdisciplinary skills were considered much more important than awareness of societal issues, communication/presentation, entrepreneurial skills or interpersonal / management. • Respondents considered interdisciplinarity crucial according to over 60%, compared to less than 20% for the other skills.
Meyyappan, 2004	US	Case Study	Educational Requirements/	• Nanotechnology, as an enabling technology, is expected to have an impact on all sectors of the economy in the 21st century, starting in a decade or so. • There is an urgent need to educate the future work force about this emerging field.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Miles, 2009	Global	Review /conceptual	Curriculum Developments; Skill Needs/ Gaps/Shortage	• Major research universities with their faculty actively engaged in nanotechnology research have the necessary expertise to assemble and offer courses in this field as evidenced by the trend in the last couple of years. • A succession of job creation and skill requirements are liable to emerge, as the core nanotechnologies are enhanced by complementary technologies and by integration into various application areas, and as dominant designs and common platforms and standards are established
Monk & Rachamim, 2005	EU	Review /conceptual	Workforce Developments; Skill Needs/ Gaps/Shortage	• One of the major challenges in building a knowledge-based economy in Europe is the availability of a sufficient number of researchers. • Taking into account the lead-time that is required to educate and train a researcher, it is clear that action is urgently needed to ensure that we do not encounter a "brain shortage" that limits our potential to realize the full benefits of nanotechnology. • The type of training required for nanoscience and nanotechnologies should often be interdisciplinary • Generally it was felt that people leaving university do not possess the skills that industry will need.
NRC, 2009	US	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage	• Academic institutions offering undergraduate education in agriculture should engage in strategic planning to determine how they can best recruit, retain, and prepare the agriculture graduate of today and tomorrow • Academic institutions offering undergraduate education in agriculture should engage in strategic planning to determine how they can best recruit, retain, and prepare the agriculture graduate of today and tomorrow • Academic institutions should broaden the undergraduate student experience so that it will integrate: • Numerous opportunities to develop a variety of transferable skills, including communication, teamwork, and management; • Several actions are necessary to prepare faculty to teach in the most effective ways and to develop new courses and curricula • Several stakeholders should take tangible steps to recognize and sup- port exemplary undergraduate teaching and related activities • Academic institutions offering teaching and learning opportunities in food and agriculture should enhance connections with each other to support and develop new opportunities and student pathways. • Colleges and universities should reach out to elementary-school and secondary-school students and teachers to expose students to agricultural topics and generate interest in agricultural careers. • Stakeholders in academe and other sectors should develop partner- ships that will facilitate enhanced communication and coordination with respect to the education of students in food and agriculture. The
Pandya, 2001	US	Empirical	Educational Requirements/ Curriculum Developments; Workforce Developments	• Currently, the need for nanotechnology workers is for MS/PhD level researchers and for technicians. • However, people whose work and training lies in between the researchers and technicians will ultimately become the workforce of the nano generation. • Two factors lead to concerns of a shortfall in the pipeline: struggles in America with STEM education, from the K12 level through graduate schools, and a lack of awareness of the nature of the nanoscale

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Roco, 2002	Global	Policy Analysis	Educational Requirements; Workforce Developments	• A key challenge for nanotechnology development is the education and training of a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress of the new technology. • It is estimated that about 2 million workers will be needed worldwide in 10-15 years from now. • The availability of sufficient scientists and industrial experts is uncertain if we continue on the current path
Sabelli et al., 2005	US	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage	• Even though the need for nanotechnology workers is currently small, it is expected to grow significantly in the near future, and can be expected to generate jobs at different skill levels. • Although these positions will require knowledge of nanotechnology concepts and skills, the job titles themselves rarely include the "nano" prefix. • Rather than consider nanotechnology as a monolithic industry, individual industries and workers should be seen as "nanoskilled;" that is, there are nanoskilled industries and nanoskilled workers in those industries. • Nanoskilled careers—implying the need for re-education and career advancement as the science and technology develops—is what we need to prepare students for.
Singh, 2007	Global	Empirical	Skill Needs/ Gaps/Shortage	• Management of R&D was identified as the most important non- technical competency • Sector based modular training through short courses is recommended for the industry especially for customer interfacing roles such as technical support. • Short training courses are recommended in basic knowledge of toxicology, health and safety of nanoparticles, and strategic application of intellectual property rights. • Policy decisions made by government and Institutions affect the trajectory of development. • Good technical understanding is essential for management in the emerging area of nanotechnology. Interdisciplinary masters level programs to include a balanced nanoscience content providing a knowledge of material science, the nano-biology interface, nanoscale effects and selected modules from chemistry. • Reponses from the industry indicated a strong preference for hands-on training experience. • New product development will form the basis of taking fundamental research and developing it novel applications. • Commercial, management and societal knowledge competencies will play an important role in the development of nanotechnology. • It is recommended that all training programs develop team working and verbal communication skills through mandatory short duration projects. • It is recommended that specific training needs of sectors such as information and communication, medical devices and health care, electronics, aerospace, automotive, energy and power are investigated in relation to nanotechnology. • It is recommended that government bodies to increase funding for encouraging knowledge partnership between industry and academia through creation of more science to business roles.

Study	Country	Type of Research Evidence	Research Focus	Main Themes and Findings in Relation to the Main Research Question
Stephan, Black, & Chang, 2007	US	Empirical	Workforce Developments;	• Our analysis leads us to conclude that at the present time the market is small and growing for positions in academe and at FFRDCs, small and stable for positions at firms. • Our analysis of training leads to the conclusion that the pipeline is being filled primarily through a principal investigator approach, where a student is attached to one faculty member's lab, rather than to a formal program. Nanotechnology promises jobs but also that labor market bottlenecks, especially at the highly skilled end, could dampen the economic returns to investing in nanotechnology. • Yet universities have been rather slow to create new degree programs in nanotechnology.
Strietska-ilina, 2008	EU	Policy Analysis	Workforce Developments; Skill Needs/ Gaps/Shortage	• Europe has already a shortage of specialists and scientists with tertiary education, and this shortage is expected to increase in the future. Experts predict that in three to five years the need for workers with related skills at intermediate level education and training will grow significantly • From the point of view of future development of the knowledge-based economy and technological change and innovation an acute shortage of people who can combine expertise in nanotechnology with strong management and entrepreneurial skills is expected
Trybula, Fazarro, & Alton Kornegay, 2009	US	Review /conceptual	Educational Requirements/ Curriculum Developments; Workforce Developments; Skill Needs/ Gaps/Shortage	• The primary skills at this stage of the development require an advanced degree(s) in science, technology, and or biology. As the development of the products move into a production stage, the supporting efforts require more of a technician background, but one with an emphasis on advanced technology. A second skill that will be required is an understanding of what the real issues are regarding safety in nanotechnology • The skills required for working in nanotechnology depend on the stage of the development of the effort. At this time, we do not know what kind of skills, simply because we are only imagining the scope of the technology required. • Workforce preparation will include collaborations between academia and research centers; while industry must commit to mutual partnerships to assist in the education and training of nano-workforce.
Wansom et al., 2009	US	Review /conceptual	Educational Requirements/ Curriculum Developments;	• What have been lacking in the nanoscale arena are commensurate developments in education reform. • While much of this workforce will come from scientists and engineers crossing over into NSE from non-nanotechnology fields, nevertheless the anticipated demand will significantly outpace the current 5% annual growth rate in the number of jobs in the U.S. labor force requiring science and engineering skills, which is already growing five times faster than the rest of the U.S. labor force
Zukersteinova, 2007	EU	Empirical; Policy Analysis; Review /conceptual	Workforce Developments; Skill Needs/ Gaps/Shortage	• Nanotechnology is still very much under development with a multidisciplinary character and, therefore, it is difficult to plan future skill needs especially at the intermediate level. • As far as specialists and scientists with tertiary education are concerned, a clear message is that Europe has already now a shortage of specialists, and this shortage is expected to increase in the future. • There is a need for monitoring intermediate skill needs and one could learn from the experience of other new and emerging technologies. • As soon as nanotechnology will go into a mass production, the shortage of skills in the intermediary level of occupations will become obvious.

Results of Stakeholder Analysis

Stakeholders in the agrifood system are wide ranging depending on the issue of concern. In this study, the stakeholders identified are those who have direct interest in or influence over workforce development in the agrifood sector. The first phase of the stakeholder analysis resulted in the specifications shown in Figure 5 and also listed in Table 6.

Figure 5. *Specifications of the First Phase of Stakeholder Analysis*

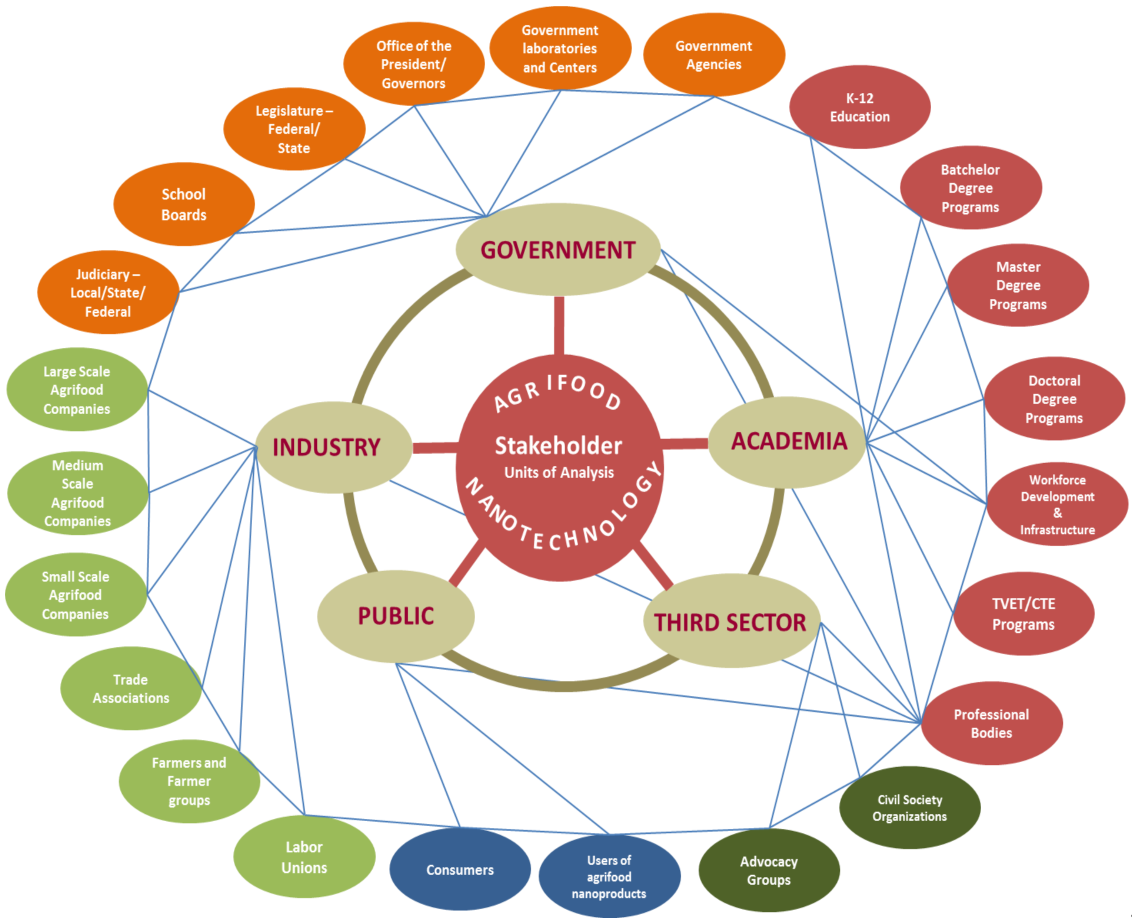

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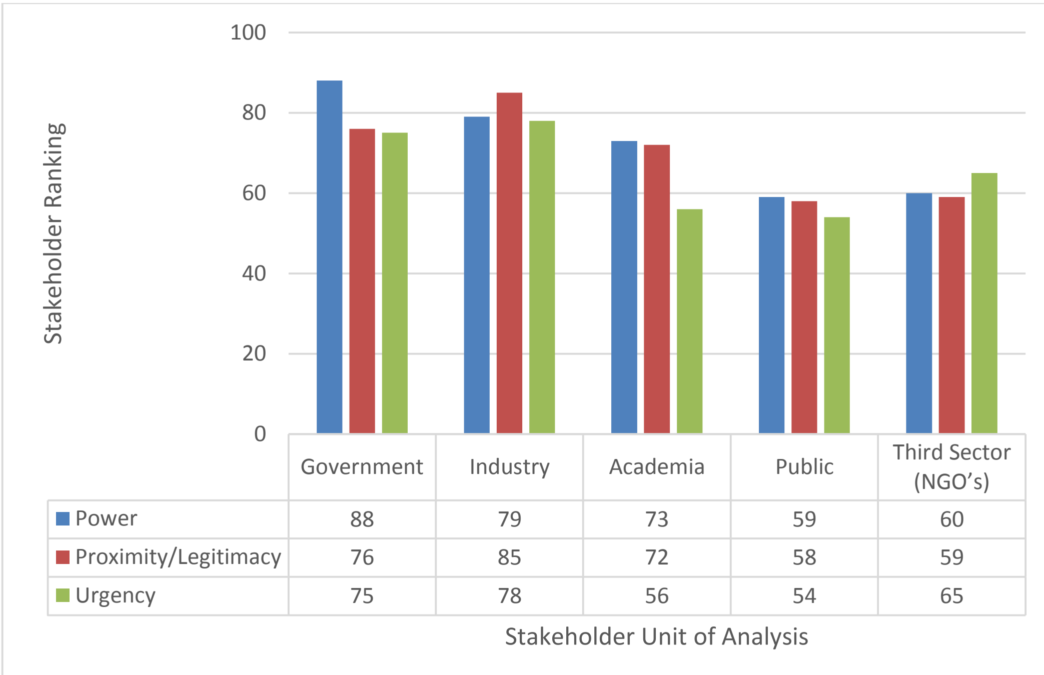
Table 6. *Agrifood Nanotechnology Stakeholder Analysis*

Stakeholder Unit of Analysis	Stakeholder Representatives
Academia	Institutions with infrastructure and programs for K12 nanotechnology Education; Institutions offering TVET/CTE certificate Programs; Institutions offering Bachelor Degree Programs; Institutions offering Master Degree Programs; Institutions offering Doctoral Degree Programs; Institutions with Nanotechnology Workforce Development Programs and Infrastructure; Professional and Academic Bodies of interest e.g. AAAE; IEEE; AHRD etc.
Government	Government (National) Laboratories and Centers Government Agencies e.g. FDA, USDA, USDL etc. Office of the President/Governors Legislature – Federal/State Judiciary –Local/State/Federal School Boards
Industry/Business	Large Scale Agrifood Companies Medium Scale Agrifood Companies Small Scale Agrifood Companies Trade Associations e.g. Chamber of Commerce Farmers and Farmer groups and Associations Labor Unions
Public	Consumers Users of agrifood nanoproducts
Third Sector	Advocacy Groups Civil Society Organizations

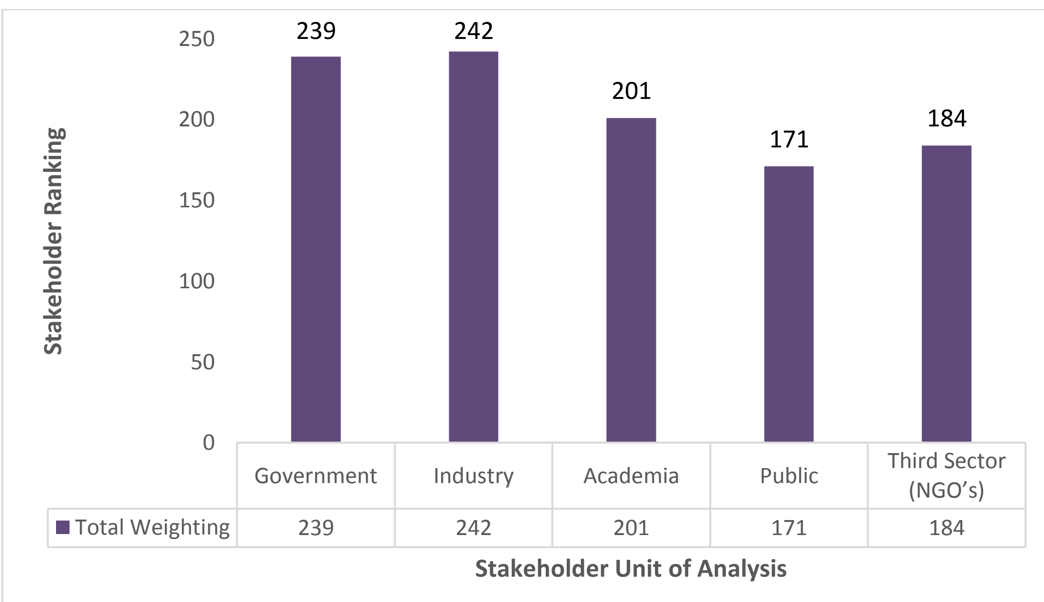
In answering the research question "who are the key stakeholders in the agrifood nanotechnology sector? Experts were made to use the following typology to prioritize the above stakeholder specification on a scale of 1 (lowest) to 5 (highest): (1) ***Powe***r—is the stakeholders' power to influence skill development in agrifood nanotechnology significant or relatively limited? (2) ***Proximity/Legitimacy***—is the stakeholder directly impacted by the consequences of action or inaction on the issue at stake i.e. skill needs for agrifood nanotechnology? (3) ***Urgency***—what is their stake? Is the stakeholder prepared to go to any lengths to address the issue at stake with or without other stakeholders? The results obtained are shown in Figures 6 - 8.

Figure 6. *Stakeholder Prioritization by Experts*



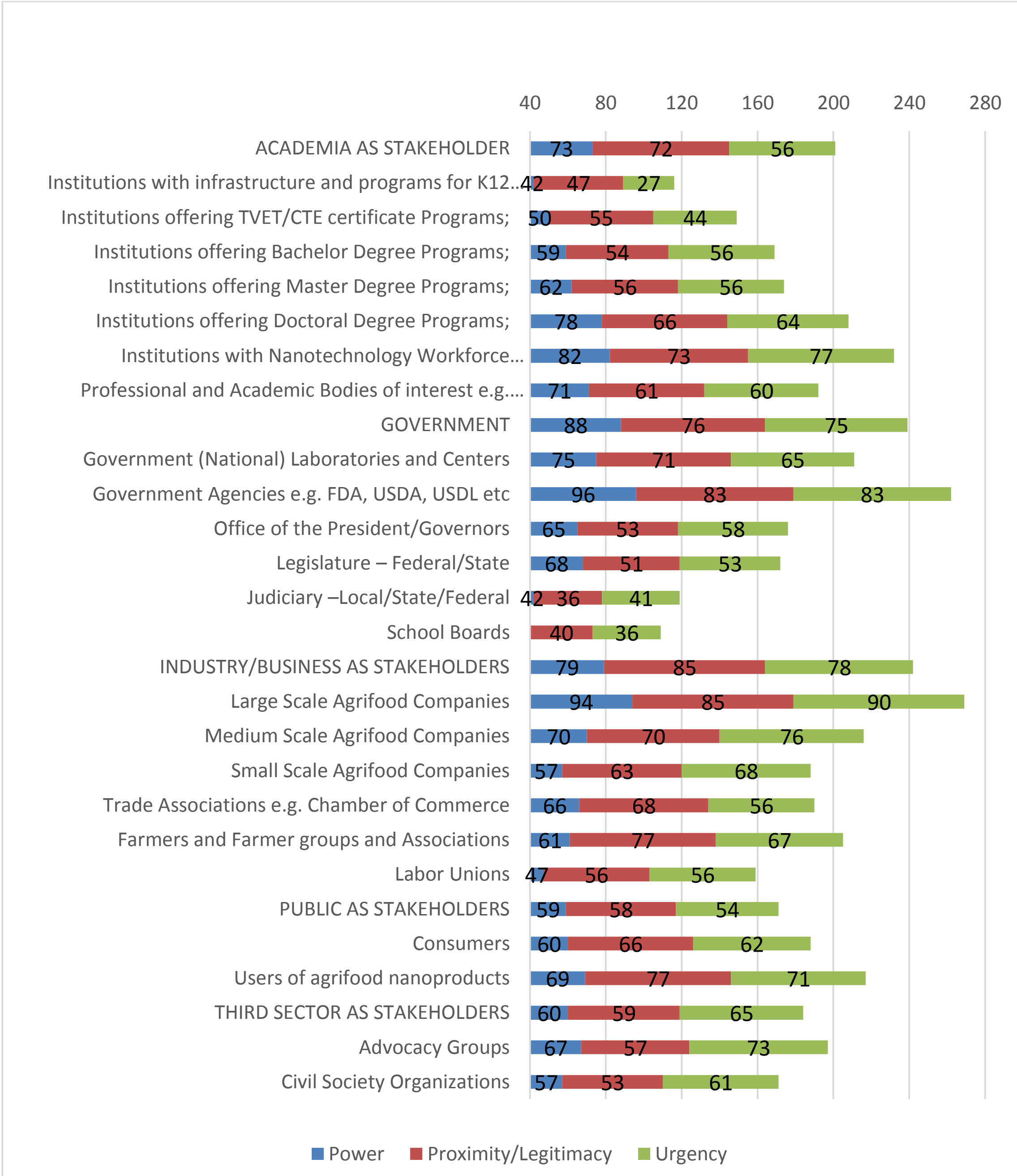
	Government	Industry	Academia	Public	Third Sector (NGO's)
Power	88	79	73	59	60
Proximity/Legitimacy	76	85	72	58	59
Urgency	75	78	56	54	65

Figure 7. *Cumulative Ranking of Stakeholders*



	Government	Industry	Academia	Public	Third Sector (NGO's)
Total Weighting	239	242	201	171	184

Figure 8. *Prioritization of Stakeholder Representatives*



Multicriteria Value Elicitation

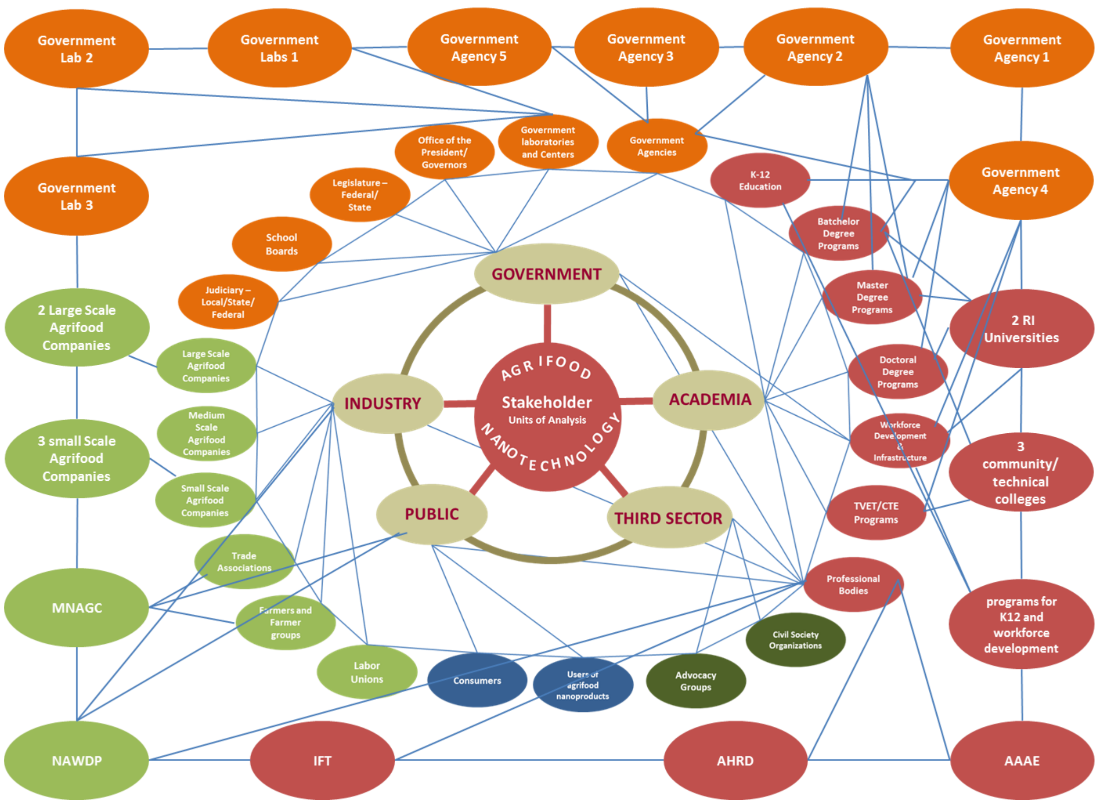
Based on the stakeholder analysis, different stakeholder groups were surveyed alongside the experts. The Experts surveyed represented all the five stakeholder unit of analysis. The stakeholder groups that were surveyed also included all the five stakeholder units of analysis either as individuals or representatives of institutions and agencies. Stakeholder groups that were surveyed included: American Association of Agricultural Education (AAAE); Institute of Food Technologists (IFT); Academy of Human Resource Development (AHRD); National Association of Workforce Development Professionals (NAWDP); Minnesota Agri-Growth Council (MNAGC); Agrifood industries; Educational institutions; and Government organizations. Table 7 shows the various stakeholders contacted and the number of respondents.

Table 7. *Stakeholders Contacted and the Number of Respondents*

Stakeholder Group	No. Contacted	No. of Respondents	Description
Education Institutions & Centers	23	7	Institutional Respondents
AAAE	N/A	70	Individual Respondents
AHRD	N/A	72	Individual Respondents
Government Institutions	11	8	Institutional Respondents
NAWDP	N/A	8	Individual Respondents
IFT	N/A	13	Individual Respondents
MNAGC	N/A	8	Individual Respondents
Industry/Businesses	68	5	Institutional Respondents
Experts	258	34	Individual Respondents
Total		**225**	

Out of the 7 respondents from educational institutions and centers 2 were representatives of RI Universities with nanotechnology programs; 3 community/ technical colleges; and 2 centers with infrastructure and programs for K12 nanotechnology Education and workforce development. The 8 respondents from Government sector included 5 from Agencies of Government Departments and three from Government laboratories. The five Businesses that responded to the survey have 2 being large scale agrifood companies and 3 being small scale agrifood companies. All the respondents from NAWDP were from industry just as MNAGC. The respondents for AAAE, AHRD, and IFT were mostly from Academia with few from Industry and also an even smaller percentage from Government. Figure 9 shows the map of actual stakeholders that were surveyed.

Figure 9. *Landscape Map of Stakeholders Surveyed*



Both experts and various stakeholder groups were surveyed using different quantitative survey instruments. The quantitative instruments developed for this study were based on instruments used for skills needs identification in the literature. Please see Appendix B for the various instruments. Key findings from the quantitative surveys were discussed with experts through qualitative interviews.

Quantitative Expert Elicitation

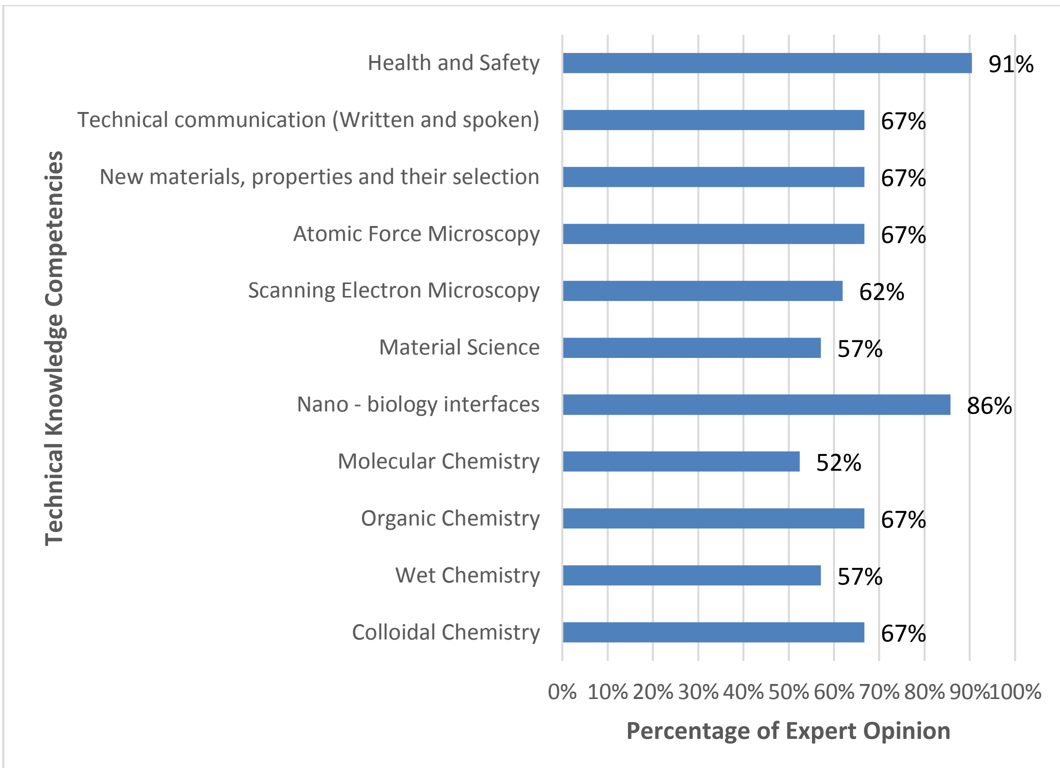
Overall 258 Experts were identified and contacted. Out of the 258 contacted, 71 responded and 34 actually took the survey. The 37 who did not take the survey gave various reasons from lack of expertise to busy time schedule. Twenty-four out of the 34 respondents were used for the analysis. Ten respondents who indicated that they were not at all involved or not very involved in agrifood nanotechnology were not used. Out of the 24 experts 18 were from Academia, one from Government, 3 from Industry, 1 from the third sector and 2 identified themselves as consumers/public.

Experts were asked to rank on a scale of 1 – 5, with 5 being most needed and 1 being the least needed, 39 agrifood employability skills and competencies that were identified in the literature as what will be needed most in the era of nanotechnology. Figure 10 shows the most needed agrifood employability skills and competencies using a cut point of 4 for the average ranking to be selected as top ranked.

Figure 10. *Experts' Ranking of Employability Skills and Competencies*

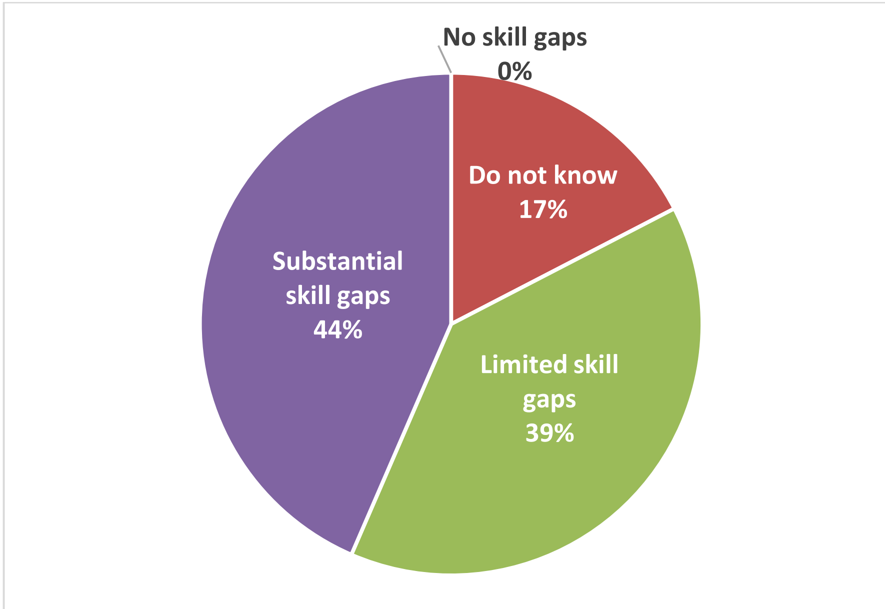
Experts were asked to select from 44 technical knowledge competencies identified in the literature which ones they would like delivered from nanoscience and nanotechnology education for placement in agrifood nanotechnology sector and Figure 11 shows the most selected.

Figure 11. *Experts Identification of Technical Knowledge Competencies*



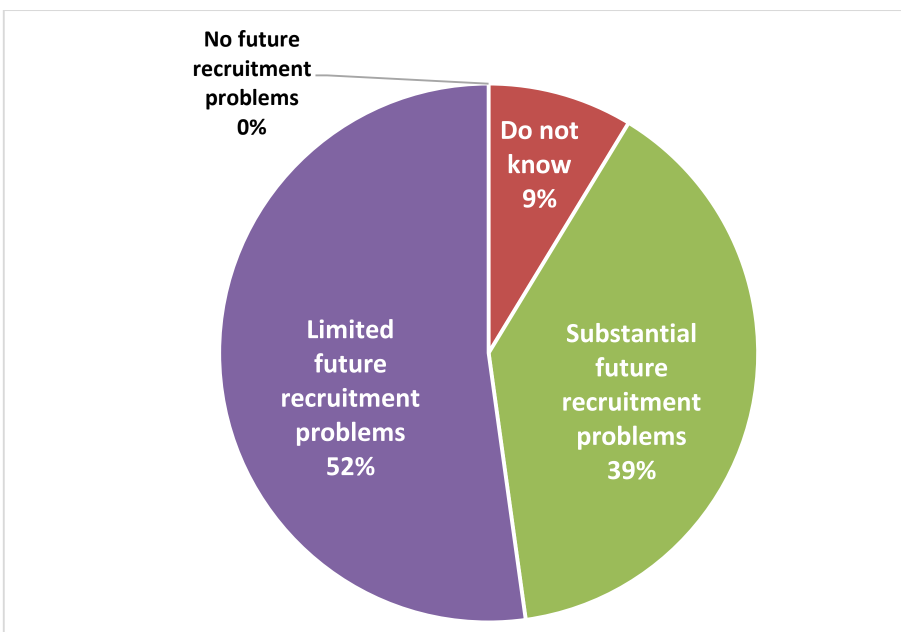
From the review of literature, skills gaps arise when the current employees do not fully meet the skills requirements for their job functions. Experts' opinion on the extent to which job-requirements stemming from developments in nanotechnology currently lead to skill gaps in agrifood industry and the results are shown in Figure 12

Figure 12. *Current Nanotechnology Job-Requirements and Skill Gaps*



Experts were asked to indicate the extent to which they expect developments in nanotechnology to lead to skill gaps in the agrifood sector in the future and the results are represented in Figure 13

Figure 13. *Experts' Opinion on Future Nanoskill Gaps in the Agrifood Sector*



Experts’ opinion was sought on the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in Nanotechnology and Figure 14 shows the results.

Figure 14. *Experts' Opinion on Best Strategy to Address Potential Skill Shortages and Gaps*

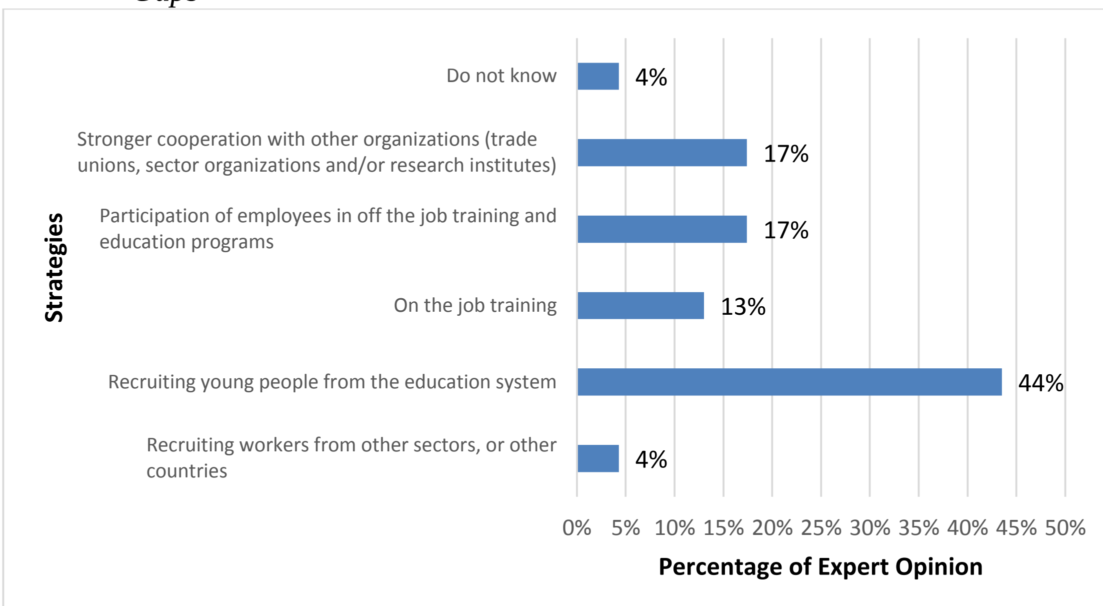
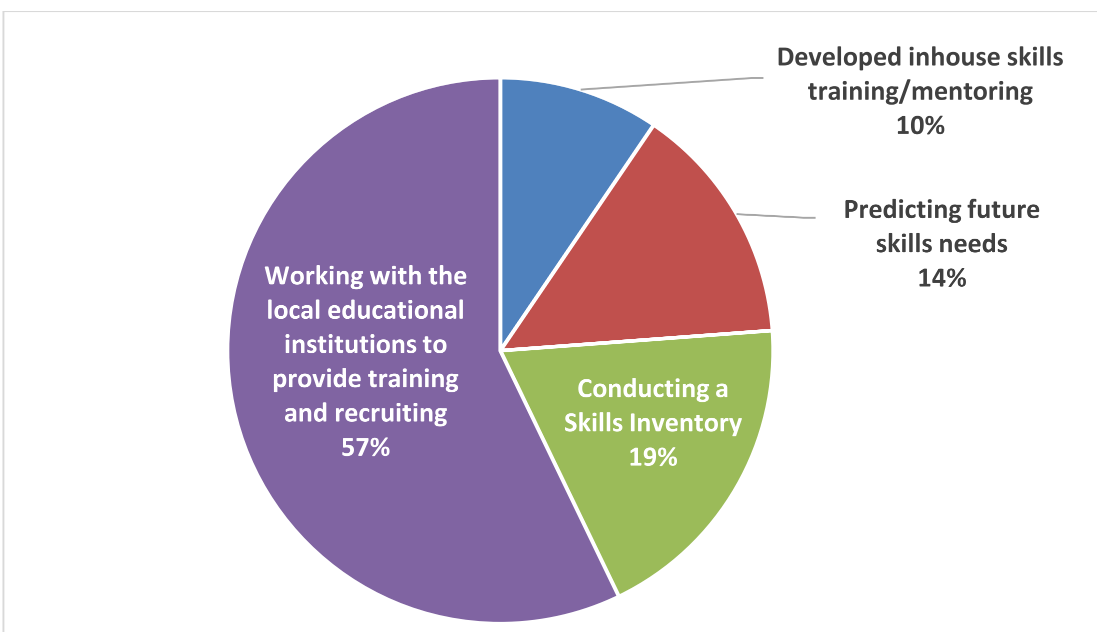
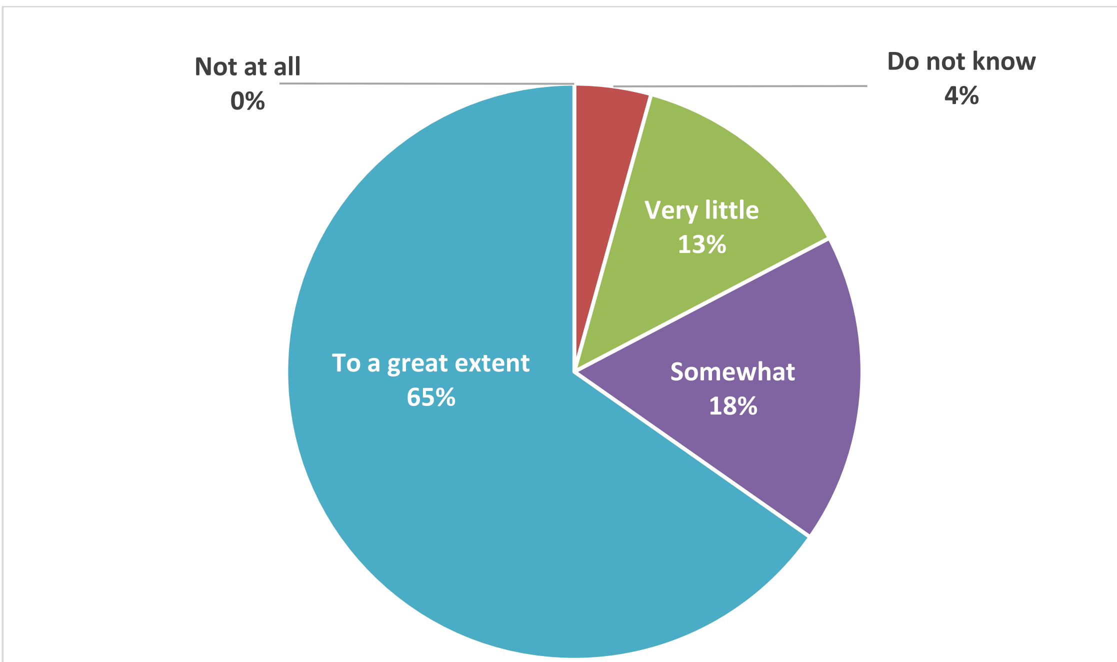


Figure 15. *Experts’ Opinion on Measures Now to Address Skill Needs*



Experts were also asked to indicate measures agrifood businesses should take now to address skill needs and the results are presented as Figure 15. Experts were then asked whether they think the higher education system (universities, polytechnics, higher vocational education) in the United States is able to fulfil skill needs related to present and future developments in nanotechnology and the results are shown in Figure 16.

Figure 16. *Experts' Opinion on Higher Education System's Ability to Fulfill Skill Needs*



On what should be improved within the higher education system to better fulfil skill needs related to developments in nanotechnology, Figure 17 shows the results from experts' opinion. Experts were also asked to indicate whether the vocational education and training (VET)/Career and Technical Education (CTE) system in the United States is able to fulfil skill needs related to present and future developments in Nanotechnology and the results are shown in Figure 18. Experts were further asked to indicate, if relevant, what should be improved within the VET/CTE system to better fulfil skill needs related to developments in nanotechnology and the results are shown in Figure 19.

Figure 17. *Experts' Opinion on Improvement in Higher Education System to Better Fulfill Skill Needs*

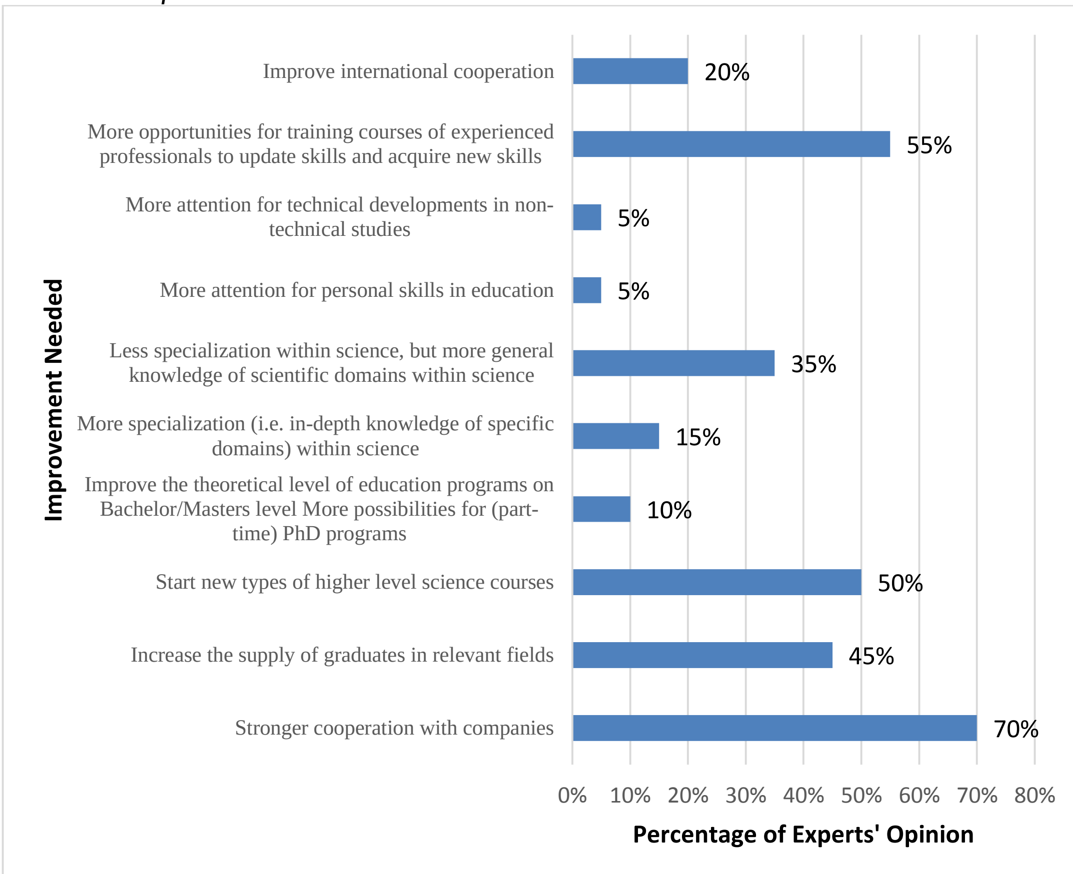


Figure 18. *Experts' Opinion on VET/CTE System's Capacity to Fulfill Skill Needs*

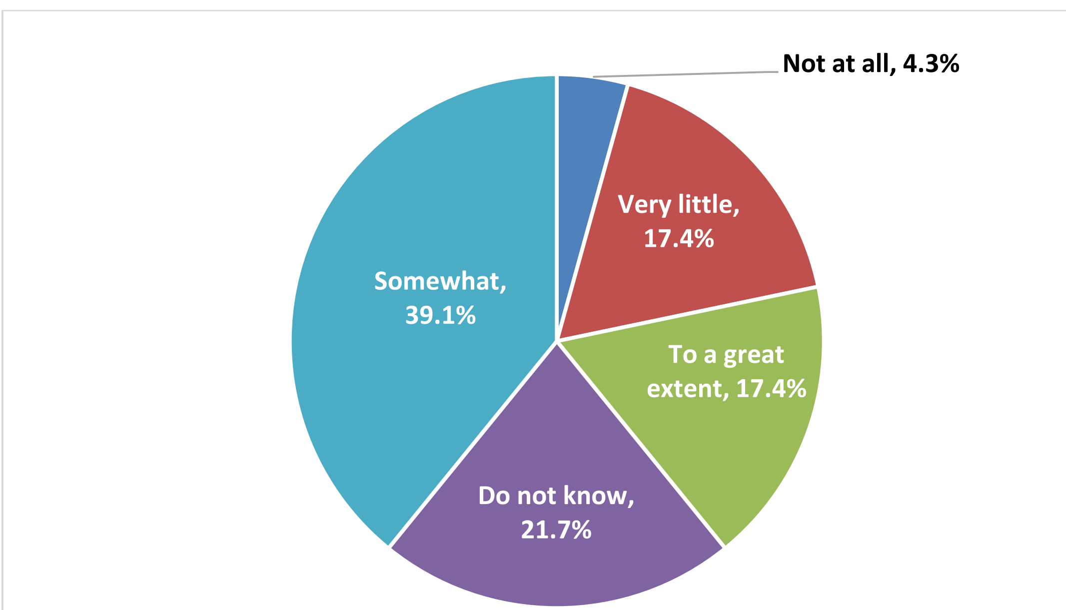
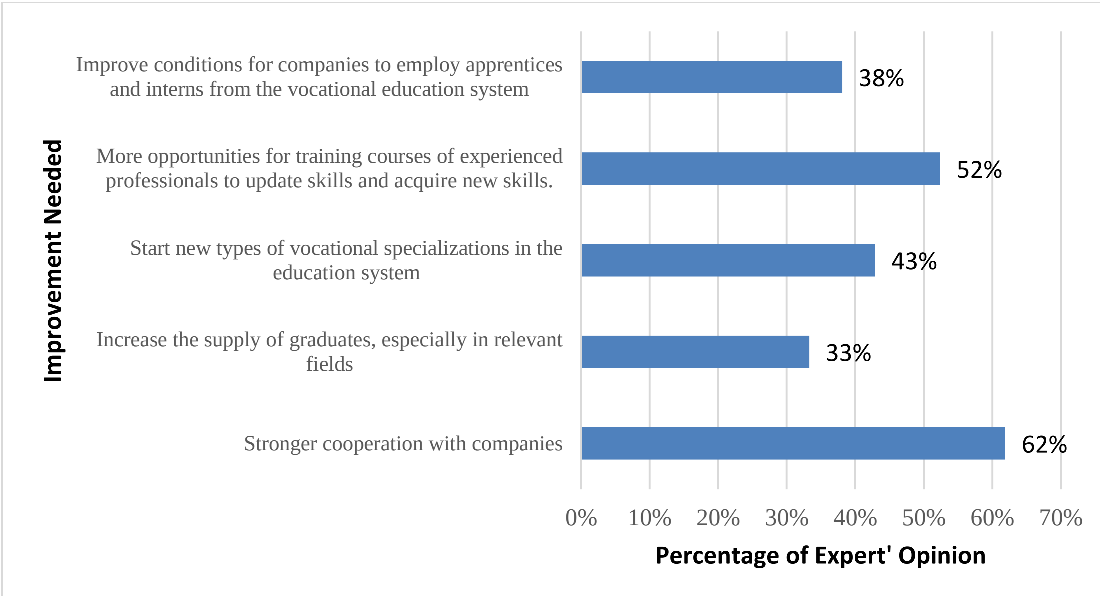
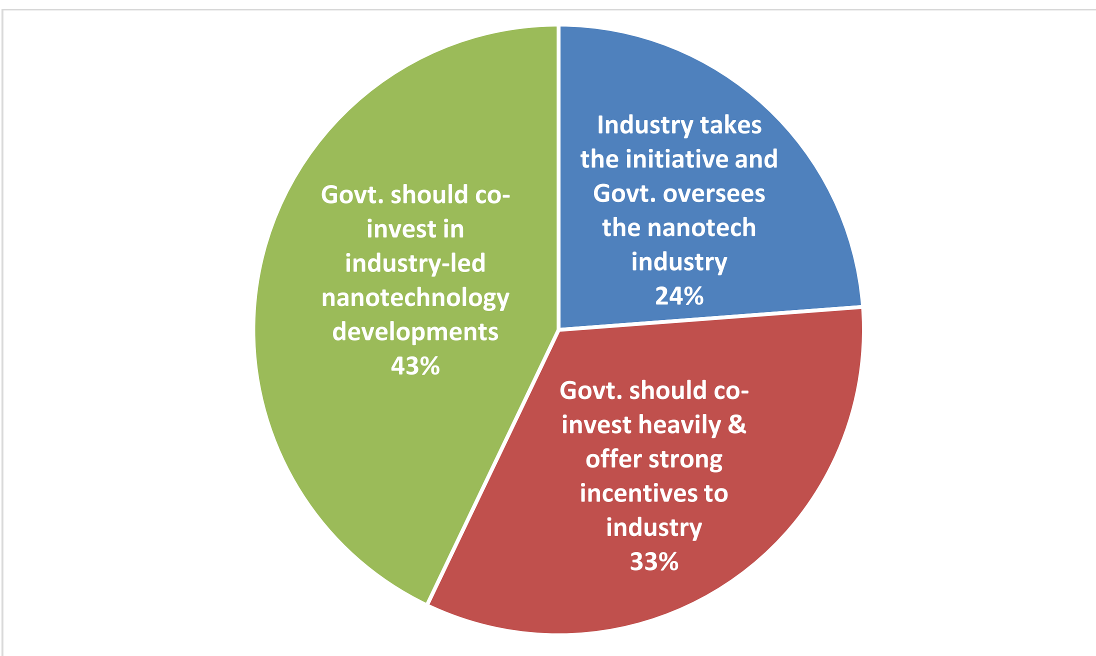


Figure 19. *Experts' Opinion on Improvement in VET/CTE System to Better Fulfill Skill Needs*



Experts' opinion was sought regarding the government's role in development of nanotechnology and the results are shown in Figure 20

Figure 20. *Experts' Opinion Regarding the Government's Role in Development of Nanotechnology*



Stakeholder Surveys

This section presents the results of the stakeholders' surveys. The results are separated into the following: the combined responses of all stakeholder groups who had individual responses (i.e. AMANI = **A**HRD + **M**NAGC + **A**AAE + **N**AWDP + **I**FT); Education Institutions; Government; and Industry.

Employability Skills: Stakeholders were asked to rank on a scale of 1 – 5, with 5 being most needed and 1 being the least needed, the same 39 agrifood employability skills and competencies that were presented to experts and using the same rating average cut off of 4. There were two forms of elicitation for industry on this question. Industry stakeholders were asked to rank the employability skills for Technicians and then do same for Graduates and Post-Graduates. See Figures 21 and 22 for the Industry ranking and Figures 23 -25 for the results of the other various stakeholder rankings.

Figure 21. *Industry Ranking of Employability Skills of Grads*

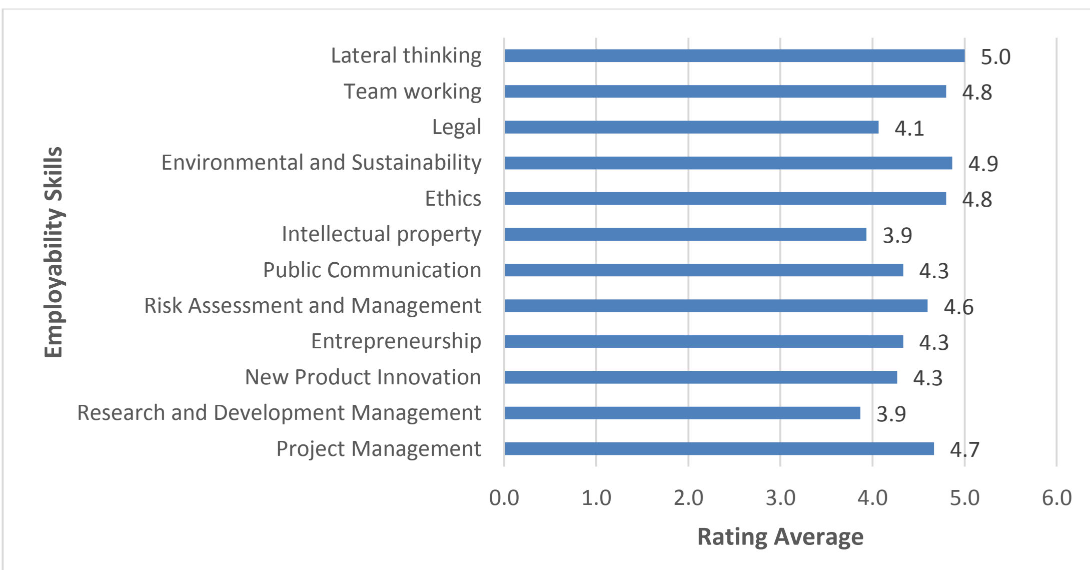


Figure 22. *Industry Ranking of Employability Skills for Technicians*

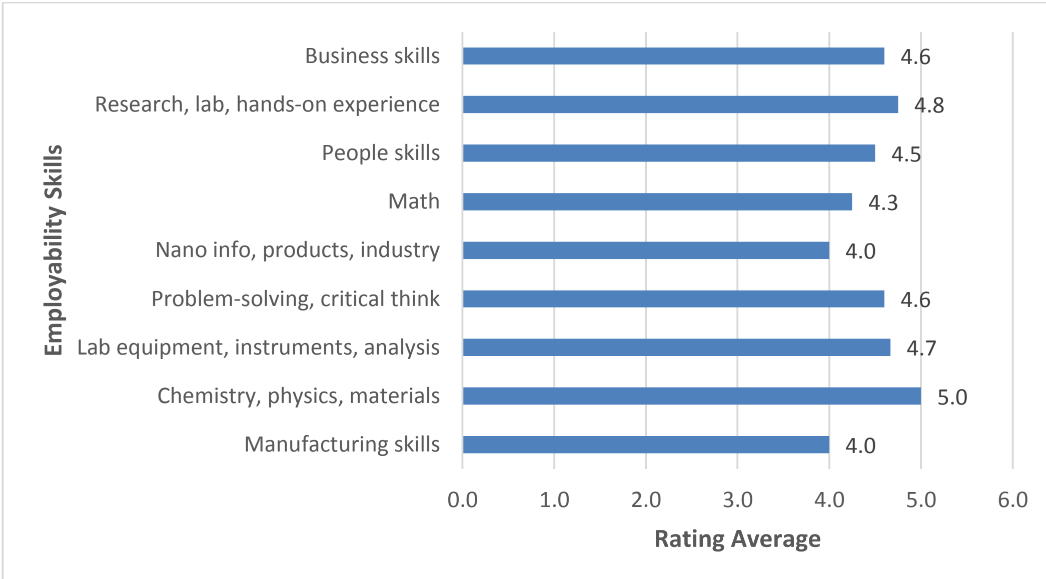


Figure 23. *Government Ranking of Employability Skills*

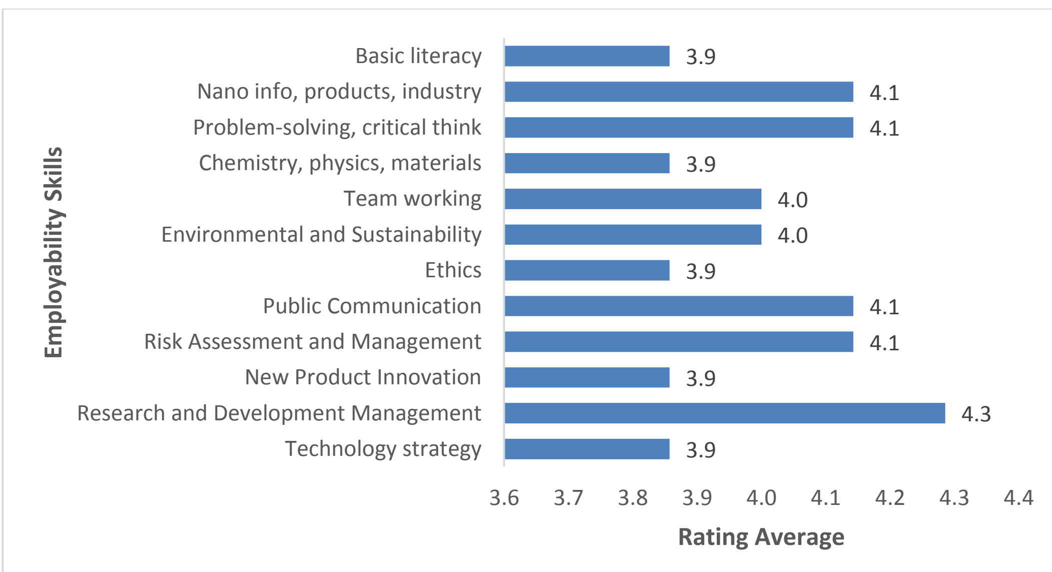


Figure 24. *Education Ranking of Employability Skills*

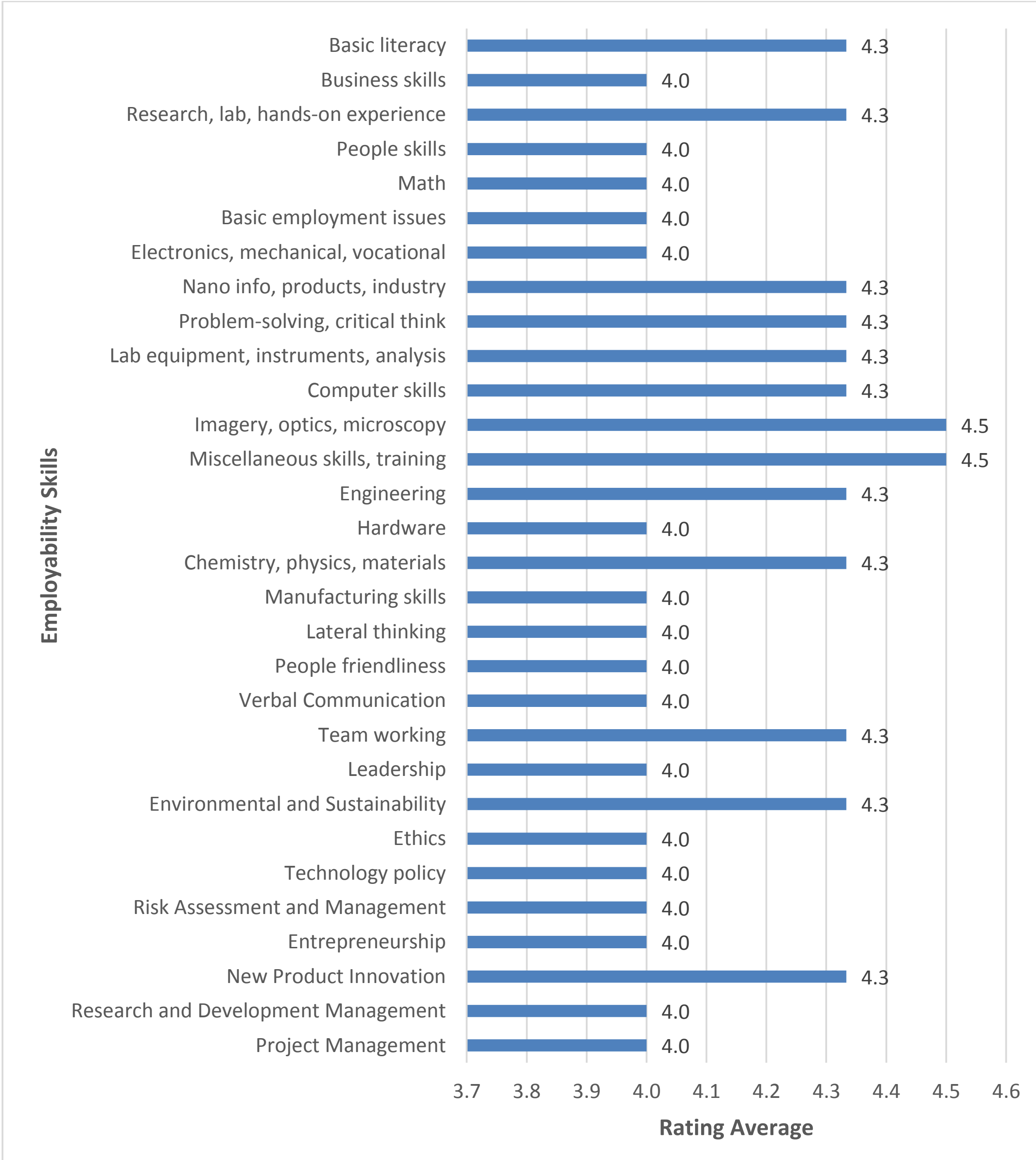


Figure 25. *'AMANI' Ranking of Employability Skills*

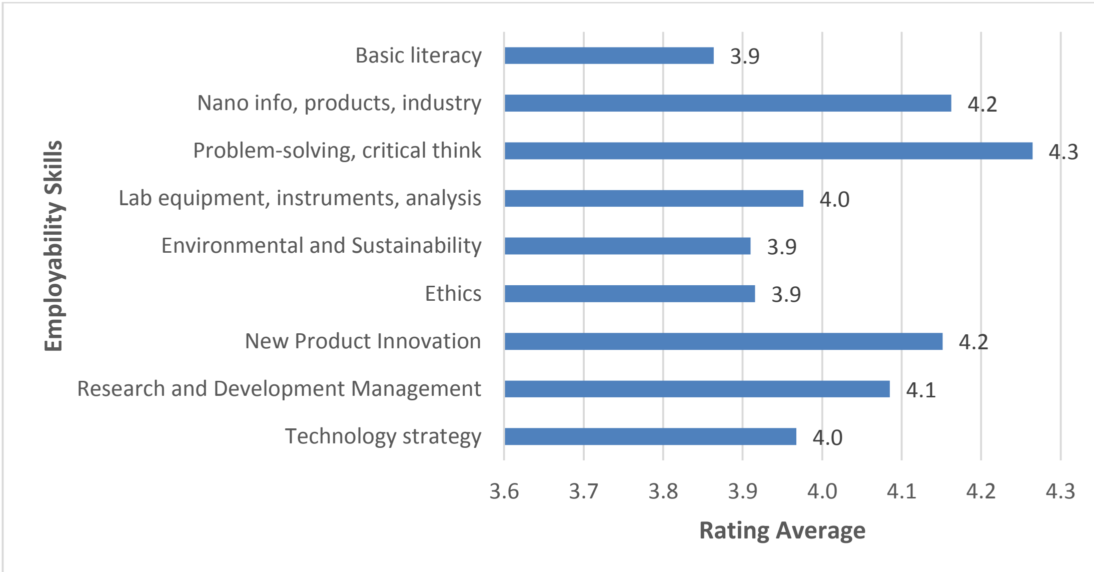
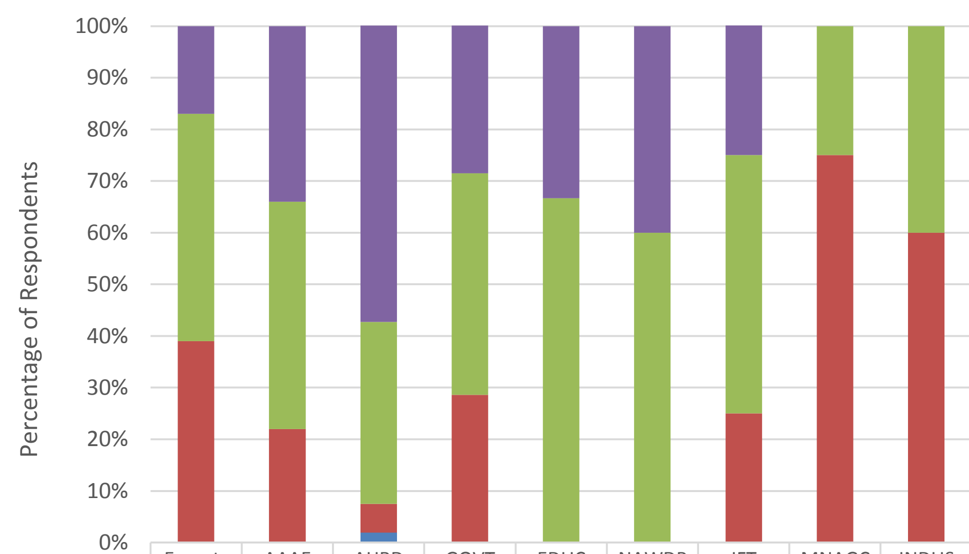


Figure 26. *Nanoskill Gaps in Agrifood Nanotechnology Industry*

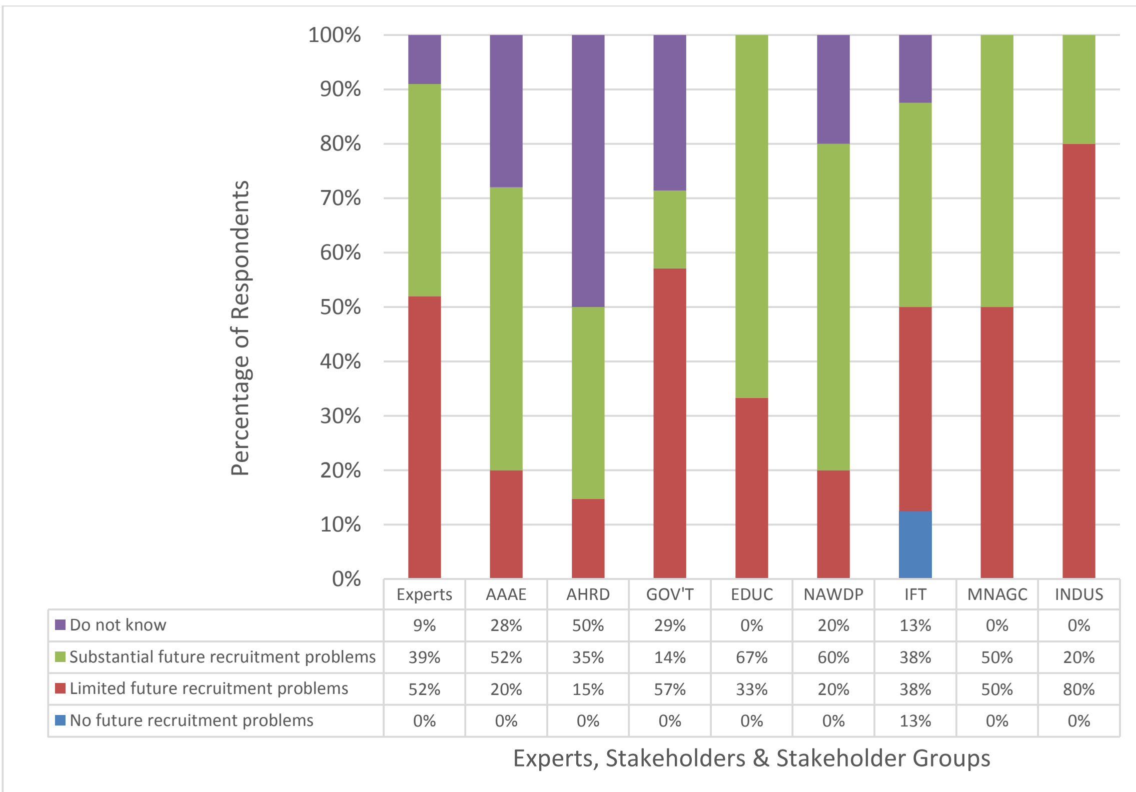


	Experts	AAAE	AHRD	GOVT	EDUC	NAWDP	IFT	MNAGC	INDUS
Do not know	17%	34%	57%	29%	33%	40%	26%	0%	0%
Substantial skill gaps	44%	44%	35%	43%	67%	60%	50%	25%	40%
Limited skill gaps	39%	22%	6%	29%	0%	0%	25%	75%	60%
No skill gaps	0%	0%	2%	0%	0%	0%	0%	0%	0%

Experts, Stakeholders & Stakeholder Groups

Impact on skills: Skills gaps arise when the current employees do not fully meet the skills requirements for their job functions. Stakeholders and stakeholder groups were asked to identify the extent job-requirements stemming from developments in nanotechnology currently lead to skill gaps in the agrifood industry and Figure 26 shows the responses. Similarly, they were asked to indicate the extent to which they expect developments in nanotechnology to lead to skill gaps and thus recruitment problems in the agrifood sector in the future and the results are shown in Figure 27.

Figure 27. *Future Nanoskill Gaps & Recruitment Problems in Agrifood Industry*



	Experts	AAAE	AHRD	GOV'T	EDUC	NAWDP	IFT	MNAGC	INDUS
Do not know	9%	28%	50%	29%	0%	20%	13%	0%	0%
Substantial future recruitment problems	39%	52%	35%	14%	67%	60%	38%	50%	20%
Limited future recruitment problems	52%	20%	15%	57%	33%	20%	38%	50%	80%
No future recruitment problems	0%	0%	0%	0%	0%	0%	13%	0%	0%

Qualitative Expert Elicitation

Further opinions of experts were elicited using semi-structured phone interviews to discuss issues that came out of the SER and also key findings from the various stakeholder surveys. The interviews were recorded and transcribed and the key themes were identified. See Appendix A for the details of the overall results of the qualitative interviews. Table 8 shows the overview of some main results of the qualitative elicitation.

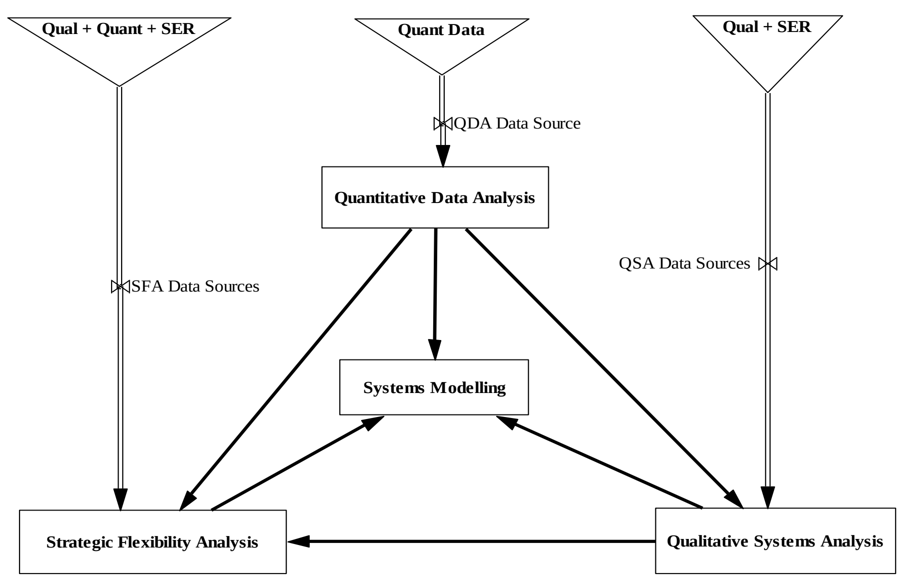
Table 8. *Overview of Some Main Results of the Qualitative Elicitation*

Subject	Main Conclusions
Skill Needs	• Future shortages and skills gaps in agrifood nanotechnology are expected to increase. At the same time there is still quite a lot of uncertainty about future developments of demand and supply. • Extra demands in high qualified workers with a background in sciences and engineering (PhD, MSc) • In addition to various types of technical skills that come with advances in any technology, and thus nanotechnology, employability skills and competencies such as problem solving and ability to work in an interdisciplinary context are considered very important.
Education (General)	• The role of nanotechnology in the education programs in Academia to increase in the next several years. • The entire educational system will need to develop new models for a nanotechnology workforce - one that crosses all disciplines. This alone will require significant investment in teacher training and curriculum development • Academia - Industry – Government partnership for curriculum development is paramount
Higher Education	• Industry are very critical about their cooperation with academia, while the perception of education institutes is that they are very active in this field. • Interdisciplinary and multidisciplinary education should be the way forward for nanotechnology education
CTE/VET	• The demand for staff with CTE/VET qualification is comparatively low at this stage. However, if ICT should serve any lesson, then there is the need for high investment in NanoVET education • The false dichotomy of preparation for work or college is no longer relevant with the emergence of nanotechnology
K-12 Education	• Incorporation of nanotechnology into STEM education initiatives should be encouraged • The current NSF K-12 nanotechnology initiatives is good and should be broadened. • Development of standards to address the STEM and to remove the existing curricula demarcations in the sciences within the overall framework of school curricula revision. • STEM education initiatives should not be devoid of employability skills

Chapter 5 – Analysis and Discussion

The analysis phase of this dissertation includes the analysis of the Systematic Evidence Review (SER), qualitative (QSA) and quantitative (QDA) data analyses; and also a Strategic Flexibility Analysis (SFA) – a scenario analysis method. All the analyses ultimately culminated in development of a generic systems model. "Scenario construction has been applied to the development of emerging technologies and socio-technical systems, including initial applications to nanotechnology" (Wiek, Gasser & Siegrist, 2009, p. 285), however, this study is the first to apply SFA to skill identification for any emerging technology. The use of QSA in this study is very relevant since skill needs identification for an emerging socio-technical system like agrifood nanotechnology is so complex that the analytical basis does not allow for only quantitative modeling (Wiek *et al*., 2008). Figure 28 shows the various analytical frameworks used and the sources of data that were used.

Figure 28. *Data Sources for the Various Analytic Approaches*



Evidence Review

From the SER it is clear that studies on skill needs identification for agrifood nanotechnology specifically is almost non-existent. In Europe, most of the research studies on skill needs for nanotechnology were conducted on a large scale by national research centers and government ministries and bureaucracies. In the United States, the very few existing ones are state sponsored taskforce reports. Actual peer-review literature on skill needs requirements for nanotechnology is almost non-existent.

However, Tessaring (2009) has stated that the identification and forecasting of future skill needs and the implementation of these needs in the context of the training and education system has perennially been a subject of rigorous research and of interest to academics, industry and government. Academic research on skills needs identification are mostly done using secondary data obtained from governmental sources. It is therefore not surprising that academic research on skills needs identification for nanotechnology is almost non-existent because current measurement issues related to nanotechnology lack the requisite information. There are several uncertainties associated with forecasts of labor demand and supply (Black 2007). There is a very lean empirical research related to the nanotechnology labor market and limited research related to emerging high-tech fields for comparative analysis (Yawson, 2010).

The United States Bureau of Labor Statistics has no data on nanotechnology workforce. To date no industrial classification (NAICS–North American Industry Classification System) exists for nanotechnology (Black 2007). “The data used to assess competitiveness in mature technologies and industries, such as revenues and market share, are not available for assessing nanotechnology" (Sargent 2008, p.1). Tessaring (2009) have further stated that:

> Societies characterized by rapidly changing social and economic conditions, increasing openness, permeability, complexity, and therefore uncertainty, are seeking new, alternative or complementary instruments for the early identification of skill requirements and their implications for the design of education, initial vocational training and continuing training. Such approaches consider the future skill requirements of target groups, enterprises, sectors and regions, and increasingly incorporate options and alternatives for policy and strategic actions. (p. 155)

Based on these contentions, Tessaring (2009) concluded that, the primary objectives of early identification of skill needs may differ and may include *inter alia:*

> 1. Projecting future developments/trends of supply and demand of existing (formal) qualifications;
> 2. Forecasting changing skill profiles in a given occupation, sector or region;
> 3. Identifying newly emerging skills and requirements;
> 4. Analyzing the increasing or declining significance of contents or elements within specific qualifications;
> 5. Detecting new configurations or bundles of skill elements in a given activity;
> 6. Taking into consideration competences (acquired formally, non-formally or informally) instead of formal qualifications, etc. (p. 155).

The main objective of the current study is identification of future skill needs and therefore the evidence review was skewed towards this objective in an attempt to answer the main research question.

Evidence review of skill needs and educational requirements

Currently agrifood nanotechnology is in a transitional phase from fundamental research to useful applications. There is still a lot of basic research going on and the emerging translational research is facing some major challenges that are attracting a lot of attention (Bugusu et al., 2006). At the current phase of development only a limited attempt at defining the medium to long term demands on employees with a middle qualification can be done. Fundamental research in high technologies like nanotechnology primarily requires employees with university education. The demand for staff with qualifications below university level is comparatively low at this stage. It has however, been found that, there is already a selective lack of qualified employees below university level in the case of agrifood nanotechnology (Abicht & Schumann, 2007).

Presently the knowledge requirements and skill components for nanotechnology are obtained from workforce with added training and additional qualifications that builds on basic qualifications in the physical, chemical or biological sciences. For the short-term it is likely that this form of training (On the Job Training) will dominate. This is because the skills needed for working in the field of nanotechnology depend on the phase of the development of the technology (Trybula, Fazarro & Kornegay, 2009).

The *National Nanotechnology Initiative* (NNI) of the United states, promotes, “A solid educational foundation, a skilled workforce, … programs continue to be developed … for all levels, including K-12 schools, community colleges, vocational schools, and major research universities” (NNI, 2009). However, there has not been any formal incorporation of nanotechnology programs into the curricula of most of these levels of education (Yawson, 2011b). It must however, be acknowledged that currently, there are a number of science, engineering, and technology programs in the United States that address the basic requirements for nano-technicians (Trybula et al., 2009). States like California, Minnesota, North Dakota, New York, Oklahoma, Pennsylvania, Texas, North Carolina and others have created two-year and four-year programs to strengthen the nanotechnology workforce development initiative to prepare for the global introduction of the emerging workforce (Cleary, 2009).

The programs are officially designed to give basic understanding of nanotechnology, the handling of nanomaterials, and the processing and production of nanoproducts. There is the need for educators to develop new approaches of workforce-training programs to give technicians the knowledge and self-assurance to be competitive on the national and international stage and the first step towards this, is skill requirements identification. At the international level, 29 institutes have been identified that deal with issues of educational research and early identification of qualification developments as at 2005 (Abicht et al., 2006). These most likely have increased exponentially since data were collected in 2005.

The US Department of Labor (USDL, 2006) has no reliable data on employment prospects in nanotechnology but has stated that the job opportunities are embedded within several occupations and most of the available job positions require longer university training. Other in-demand occupations were projected for 2-year-university-trained personnel such as sales representatives, manufacturing, and technicians with different specialties. Recent anecdotal evidence from the USDL's Occupational Information Network (ONET, 2010) points to the emergence of new occupational requirements exclusive to nanotechnology such as Nanotechnology Engineering Technicians and Technologists, Nanosystems Engineers, as well as a rising demand for nanotechnology skills within the context of other occupations.

The Sector Skills Council for Science, Engineering and Manufacturing Technologies (SEMPTA 2009) in the UK completed an assessment of the skills required for advanced manufacturing and found that as a result of nanotechnology application in industry being in its infancy, current skills requirements are focused on R&D, together with a knowledge base in intellectual property and new product development. SEMPTA (2009), however, concluded that, the increasing rate of manufacture of nanomaterials is leading to rising demand of highly skilled technicians capable of using complex equipment.

It is clear from the SER that the primary technical skills at this stage of nanotechnology development require an advanced degree(s) in the physical, chemical, and/or biological sciences. As the development of nanotechnology moves more into production and marketing stages, the supporting roles will need more of a technician background. The most important, however, is that employability skills will be even more important and most of skills gaps or shortages that may occur in the future may be lack of trained agrifood workforce with employability skills.

Empirical Research

The Institute of Nanotechnology (U.K.) conducted a "Nanotechnology Skills and Training Survey" to identify the skills gaps and training needs of the workforce in the emerging area of nanotechnology (Singh, 2007). As part of the objectives of the study were to: "(1) Identify the current and prospective roles of graduates and post-graduates, along with the professional development needs; and (2) Inform education and training Institutions of the gaps and latent needs" (p. 15). The study was based on qualitative and quantitative analysis of 61.2% of the total 240 responses received. According to the study, doctoral qualifications were considered to be the preferred knowledge level and that both generalist and specialist skill sets were valued by employers. Lack of availability of workforce with the suitable skills and right knowledge depth was considered a major problem. The study used a five-step process of design, feedback, circulation, qualitative information gathering and analysis as the methodological approach.

In an Europe wide study by *Nanoforum* with a total of 749 respondents (93% from 32 European States) 68% of respondent indicated that Europe may face a shortage of skilled research personnel for nanoscience and nanotechnology in 5-10 years and 80% of respondents identified further training opportunities and mobility for researchers as important (Malsch & Oud, 2004).

As part of an on-going study to determine the human capital available in each country that is suitable for nanotechnology, Burnett and Tyshenko, (2010) are using the number of tertiary graduates, those graduates from universities, colleges and vocational schools in science and engineering. According to the study:

> The percentage of graduates will determine how each country's population is relatively prepared for a nanotech industry or whether the country can support a base pool of people versed in nanotechnology. The number of graduates will determine, in absolute terms, which country has a higher level of human capital suited for nanotechnology (p. 190).

The study defined Human Capital, based on the description by the Organization for Economic Cooperation and Development (OECD, 2007) that human capital is the skills available in the population and labor force. The study further identified with Colombo and Grilli's (2005) explanation that this skill available in the population and labor force is a mix of generic and specific skills, formal education and work experience. Colombo and Grilli (2005) further explained that generic human capital is a person's general knowledge acquired from formal education and work experience whereas, specific human capital is a person's unique capabilities such as knowledge of the industry and entrepreneurial skill.

As part of a longitudinal and ethnographic study with the main outcome of developing an associate degree level skill set that qualifies a person as a Nano-Technician for a broadly-trained nanotechnology workforce, "the Center for National

Nanotechnology Applications and Career Knowledge (NACK) conducted intensive interviews and surveys involving more than 200 companies over nearly ten years spanning virtually all industries using nanotechnology across the nation" (p.1). The skill set identified by the study for a Nano-Technician includes the following:

- safety, and environmental protection awareness;
- foundation skills such as equipment use and maintenance as well process design and control;
- foundation skills in pattern transfer including block co-polymer techniques and optical, e-beam, and ion beam lithography;
- fabrication skills including both bottom up (e.g., self-assembly, catalyzed nano-wire growth, colloidal chemistry) and top-down (e.g., etching, deposition, materials modification) processing;
- characterization skills (e.g., optical, scanning probe, and electron microscopy); and
- professional skills (problem solving, project management, team building, research methods, IP awareness, report writing, and presentation skills) (NACK, 2010, p.1)

According to NACK, a technician endowed with these skills will have finished a wide, hands-on educational experience and is fully prepared to work for any nanotechnology enabled industry, including the electronics, agriculture, food, biotechnology, pharmaceuticals, energy, materials manufacturing, and chemical industries.

A study conducted by John J. Heldrich Center for Workforce Development at Rutgers University of New Jersey (Horn & Fichtner, 2008) based on interviews and input from more than 50 companies, educators, and other stakeholders in Phoenix and Tucson, Arizona, investigated the consequence that nanotechnology is having on the workforce requirements of companies and educational institutions involved in nanotechnology research in Arizona. Data obtained for this study came from responses to an online inquiry, in-depth interviews with more than 25 individuals, and what the researchers referred to as "a progressive dialogue with educators and stakeholders" (p. 1).

In another study by the John J. Heldrich Center for Workforce Development at Rutgers University of New Jersey (Horn, Cleary & Fichtner, 2009), a preliminary findings on the workforce and skill needs of two large pharmaceutical companies based in New Jersey indicated that "nanotechnology has affected the skill and knowledge needs of several different classes of workers, albeit often in moderate ways" (p. 1). The study found that Research and Development (R&D) workers were the most highly and directly affected by nanotechnology. The study further claimed that "workers in manufacturing and corporate positions have also had to acquire new knowledge and skills relevant to nanotechnology in the pharmaceutical industry" (p.1). The study used expert elicitation approach based on "four in-depth interviews with corporate executives, a research fellow, and a manufacturing plant manager" (p.1).

A study by Vanston and Elliott (2003) was "designed to provide Texas community and technical college instructional officers and curriculum development coordinators/directors with timely analysis and actionable insights into nanotechnology and its anticipated impact on existing and new technical educational curriculum" (p. iv). The study was conducted on the premise that:

> A highly skilled workforce is essential to the success of Texas companies and the overall economic competitiveness of the state. Therefore, by anticipating and proactively responding to future Texas workforce demands, community and technical college curriculum offerings can be a constructive force in attracting high-tech companies to the state and ensuring existing high-tech companies continue to have an appropriately skilled source of employees (p. iv).

The main objective of this research which was a contract study for the State of Texas was to drive the development and support of nanotechnology curriculum and facilitate informed and accurate future curriculum development efforts for all Texas community and technical colleges in the newly emerging field of nanotechnology. The research was a forecast study to determine the skill needs of nanotechnology and this was done in a three-step methodological process of extrapolation techniques, literature searches, and expert elicitation.

In a study to identify skill needs in nanotechnology, Abicht, Freikamp, and Schumann (2006) reviewed estimates and forecasts of the significance and scientific-technological developments of nanotechnology in various fields. The study analyzed future demand for skills in the nanotechnology labor market, indicated major sources and institutions involved in investigating the future demand for appropriate qualifications, and presented a review of research results on specific and basic skills, particularly of innovative skills required and emerging new occupations as a result of nanotechnology.

In a study by the Victorian Department of Innovation, Industry and Regional Development (DIIRD) to determine nanotechnology skills capabilities requirements for Victoria, Australia, it was identified that skills for future nanotechnology workers includes: "The ability to work in a multi-disciplinary science team; problem solving and project management skills; science communication skills; enterprise and business awareness; and, industry awareness and R&D skills" (DIIRD, 2003, p.4). The study used a methodology involving two parallel processes:

1. A desktop review of existing education and training opportunities including models from interstate and overseas. This review also mapped educational pathways for both VET and Vocational Education providers" (p.7).
2. "Interviews with CEOs and/or research managers of companies that use nanotechnology R&D and interviews with university academics and research institution scientists (p.7).

Abicht (2009) conducted a survey of 178 German nanobusinesses in a study to determine the qualification structure and demand for further education of German nanotechnology companies and found that over half of the employees of these companies hold University degrees. Abicht (2009) concluded that the implication is that the firms are highly research-intensive. The study found that the remaining employees consisted of skilled workers (20%), master craftsmen and technicians (10%), with fewer than 10% in administrative or unskilled jobs. In terms of expectations, the firms thought that the share of skilled workers would rise with the shift from research/development to production/service. The foregoing empirical evidence from the systematic review also clearly shows that both technical and employability skills is needed.

Quantitative Data Analysis

Thirty nine employability skills were identified through the literature. The thirty-nine employability skills are categorized under three main employability skills and competencies construct: Commercial, management and societal knowledge competencies; Soft Skills; and Technical Skills. Experts and stakeholders ranked the employability skills and competencies with the objective to better understand the skills needed in the agrifood nanotechnology workplace. The employability skills and competencies were ranked from high to low to determine the most needed, which is an indication of where new curriculum for agrifood nanotechnology should pay more attention. The quantitative data were coded to facilitate data entry. I analyzed the data using the Statistical Package for the Social Sciences (SPSS) version 19.0 computer program for windows and also the inbuilt statistical analysis package within the survey monkey software ‘gold package’.

The quantitative data obtained from the experts and stakeholder surveys were analyzed using descriptive statistics. This is due to the small sizes of data that were obtained from some of the stakeholder surveys. To determine the agrifood employability skills and competencies that will be needed most in the era of nanotechnology, average rating scores were calculated from the data on the employability skills and competencies.

$$R = \frac{x_1 + 2x_2 + 3x_3 + 4x_4 + 5x_5}{5}$$

Where R is the rating average; and *x* is the number of respondent for each ranking on the scale of 1 – 5. The rating average was important for comparison as different stakeholder groups have different sample sizes. Please see Appendix D for the rating averages of the experts and the stakeholder groups' responses.

Qualitative Systems Analysis

A qualitative systems analysis was done in line with the theoretical underpinnings of this study (i.e., systems theory and complexity theory). The QSA included two main steps: (i) identification and selection of system variables and (ii) qualitative analysis of the mutual interactions among the variables - an impact analysis (Wiek, Lang, & Siegrist, 2008). The causal-functional dynamics associated with skill needs identification for an emerging socio-technical system like agrifood nanotechnology accentuates the importance of systems dynamics modeling. The conceptual framework for developing the systems model for this study is compatible with well-known indicator frameworks discussed and further developed, for instance, in Pope, Annandale, and Morrison-Saunders (2004); and Wiek and Binder (2005) as cited and described by Wiek et al. (2008). In this study four categories of system variables were identified from the qualitative data from the SER and the multicriteria value elicitation using thematic coding. This follows the framework used by Wiek et al.

(2008). The the strengths of the impact on skill were subjectively evaluated using an ordinal scale from 0 to 2, where 0 means no impact, 1 a weak impact, and 2 a strong impact. This three-digit scale was appropriate for distinguishing between strengths based on the quantitative and qualitative data from the expert elicitation. A similar three digit scale has been used in previous studies (Wiek et al., 2008)

Focus variables (FV)

This set of variables includes the functional typologies of currently emerging nanotechnology applications in the agrifood system obtained from the literature and expert elicitation, which represent the starting point of the analysis. Determining a functional typology of agrifood nanotechnology applications helped to aggregate specific applications with similar characteristics into general skill requirements bracket (Wiek *et al*., 2008). Table 9 shows the final focus variables.

Table 9. *Description of Focus Variables.*

Code	Variable	Nanotechnology	Function	Impact on Skill
FV1	Nanostructured (also termed nanotextured) food ingredients	Processed nano- structures in food	Novel or improved tastes, flavors, textures	2
FV2	Nanodelivery systems for nutrients and supplements	Nano-encapsulated bioactive substances in the form of nanomicelles, liposomes or biopolymer-based carrier systems – mainly additives and supplements for food and beverage products.	The nanocarrier systems are used for taste masking of ingredients and additives such as fish oils, and protection from degradation during processing. They are also claimed for improved bioavailability of nutrients/ supplements, antimicrobial activity, improved optical appearance, and other health benefits.	2
FV3	Organic nanosized additives for food, health food supplements, and animal feed applications	Organic additives (many of them naturally occurring substances) manufactured in the nanosize range.	Due to larger surface area, lower amounts would be needed for a function, or a taste attribute.	2

Code	Variable	Nanotechnology	Function	Impact on Skill
FV4	Inorganic nanosized additives for food, health food supplements, and feed applications	Inorganic additives manufactured in the nanosize range	Due to larger surface area, lower amounts would be needed for a function, or taste attribute. Other projected benefits include antimicrobial activity etc.	2
FV5	Food packaging applications	Plastic polymers containing (or coated with) engineered nanomaterials for improved mechanical or functional properties.	Improved mechanical and functional properties of polymers used as food contact materials or in food packaging.	2
FV6	Nanocoatings on food contact surfaces	Nanoscale coating.	Nanocoatings for FCMs with barrier or antimicrobial properties.	2
FV7	Surface functionalized nanomaterials	The 2nd generation nanomaterials that add certain functionality to the matrix, such as antimicrobial activity, or a preservative action, such as through absorption of oxygen.	For food packaging materials, functionalized ENMs are used to bind with the polymer matrix to offer mechanical strength or a barrier against movement of gases or volatile components (such as flavors) or moisture.	2
FV8	Nanofiltration	Filtration products based on porous silica, regenerated cellulose membranes.	Filtration of undesired components in food – such as bitter taste in some plant extracts. Also clarifying wines and beers.	2
FV9	Nanosized agrochemicals	Nanosized fertilizers, pesticides, veterinary drugs	Improved delivery of agrochemicals in the field, better efficacy of pesticides, and better control over dosing of veterinary products.	2
FV10	Nanosensors for food labeling	Incorporation of nanomaterials into intelligent inks (that respond to a change in the packaged food) to print labels that can indicate the safety and security of the packaged foodstuffs.	Sensors that can monitor condition of the food during transportation and storage.	2
FV11	Water decontamination	Nano-iron, other photocatalysts may also be used	Water treatment	2
FV12	Wireless nano-networks in agricultural fields, pesticide capsules	Nanotechnology applications that improve the agricultural output per area or/and time or/and input	Increase of agricultural efficiency	2

Note: The listing of these variables were adapted from FAO expert group report on nanotechnology as was recommended by experts through the qualitative elicitation.

Context variables (CV)

As shown in Table 10, this set of variables is defined by the relevant factors influencing the development of agrifood nanotechnology applications with direct impact on future skill requirements. These variables include both historical antecedents and anticipated skill needs.

Table 10. *Description of Context variables (CV).*

Code	Variable	Description	Impact on Skill
CV1	Development potential	Global know-how and infrastructure for R&D of nanotechnology.	2
CV2	Public awareness	Public awareness of agrifood nanotechnology, including basic understanding, perception of risks/benefits, and acceptance.	1
CV3	Consumer acceptance and demand	Consumer acceptance, demand and choices of agrifood nanotechnology, including habits, preferences, and values.	1
CV4	Laws and regulations	The legal framework for the development and use of nanotechnology, including laws, policies, executive instruments, and self-regulations.	2
CV5	Public investment	The amount of public resources allocated to R&D in agrifood nanotechnology.	2
CV6	Profit potential	The assumed business potential of nanotechnology applications, indicated by the worldwide private financial investments in nanotechnology.	1
CV7	Academia-Government-Industry Collaboration	Linkages between government, academia and industry to enable collaboration as a means through which one can address complex issues associated with agrifood nanotechnology.	2
CV8	Risk assessment	The available results provided by independent risk assessments on agrifood nanotechnology.	2
CV9	Public participation	The official involvement of society in scientific, governmental and industrial decision processes on agrifood nanotechnology.	1
CV10	Educational policy & Curriculum Development	Policies and a series of courses that help learners achieve specific academic or occupational goals in agrifood nanotechnology	2

Target variables (TV)

This set of variables, as shown in Table 11, consists of the relevant occupational profiles in the agrifood systems that are or might be impacted directly by nanotechnology applications and thus direct nanoskill needs. Due to long list of occupational profiles within the agrifood cluster, I used the ONET categorization of occupational profiles into broad career pathways as the variables.

According to ONET "Career Clusters contain occupations in the same field of work that require similar skills and thus students, parents, and educators can use Career

Clusters to help focus education plans towards obtaining the necessary knowledge, competencies, and training for success in a particular career pathway"(ONET, 2013).

Table 11. *Target Variables (TV)*

Code	Variable	Occupational Profiles	Impact on Career Pathway
TV1	Agribusiness Systems	See appendix E for occupational profiles in the various career pathways	1
TV2	Animal Systems		2
TV3	Environmental Service Systems		2
TV4	Food Products and Processing Systems		2
TV5	Natural Resources Systems		2
TV6	Plant Systems		2
TV7	Power, Structural and Technical Systems		1

Action variables (AV)

This set of system variables consists of programs and policies in place to address nanoskill needs by industries (see Table 12). This set of variables is defined by the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in Nanotechnology.

Table 12. *Action Variables (AV)*

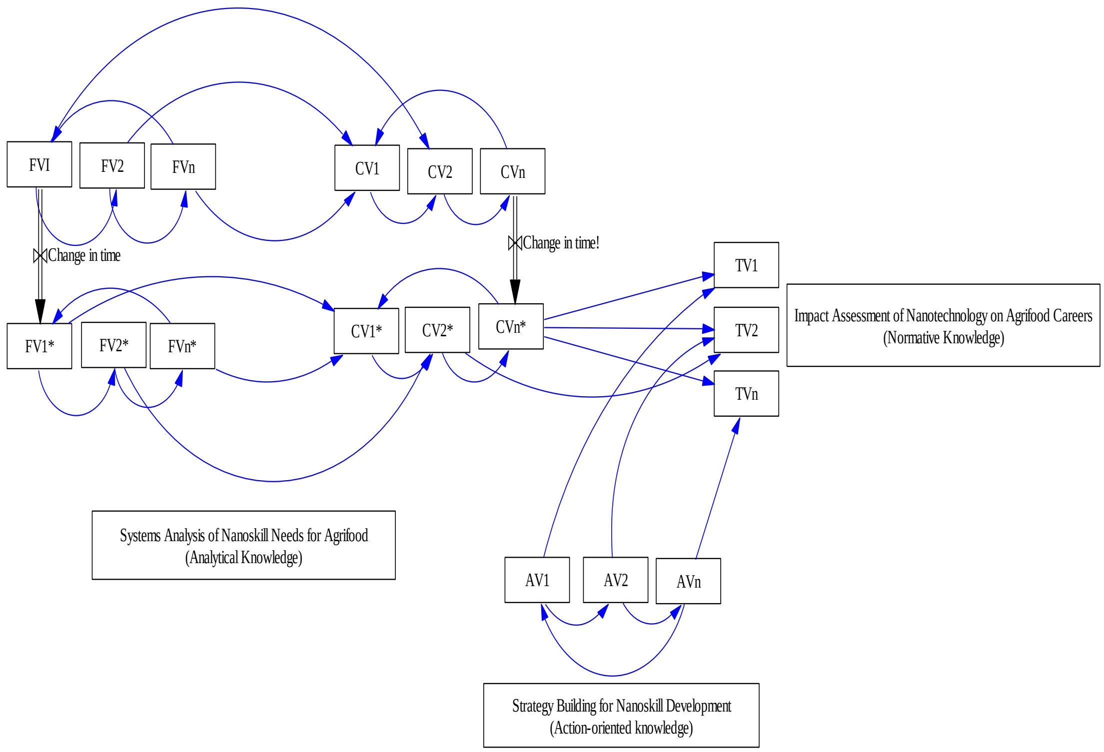
Code	Variable	Impact on Skill
AV1	Increase wages	0
AV2	Further automation and mechanization to substitute labor	0
AV3	Try to postpone retirement older employees	0
AV4	Recruiting workers from other sectors, or other countries	0
AV5	Recruiting young people from the education system	2
AV6	Use of specialized agencies/temporary workers/ headhunters	0
AV7	Restructuring the (work) organization	0
AV8	Increase internal job mobility in the company	0
AV9	Outsourcing and off shoring	0
AV10	On the job training	1
AV11	Participation of employees in off the job training and education programs	1
AV12	Stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes)	1

Impact Analysis

An impact analysis was done to subjectively estimate the direct impacts of each variable on agrifood skill requirements, and also each variable on the others using Vensim™ Systems Dynamics Software for Windows. Each link contains information about the strength and quality of the impact between two variables. As mentioned earlier, the strengths were subjectively evaluated using an ordinal scale from 0 to 2, where 0 means no impact, 1 a weak impact, and 2 a strong impact.

The strengths of Focus, Context, and Target variables were subjectively determined based on qualitative expert elicitation. The strength of impact of the Action Variables were obtained using quantitative elicitation data (See Appendix B, question 9 of the quantitative Expert Elicitation Questionnaire). In the case of the Target Variables the impact was determined for the career pathway as a whole and not the skills required. The impact analysis helps to understand the systemic particularities of functionally different nanoskill requirements. Figure 29 depicts the causal-functional framework of system variables corresponding to the stages of developments in agrifood nanotechnology and resultant skill needs (system analysis, future projection/scenario construction, impact assessment, strategy building), and possible causal relations between the variables.

Figure 29. *Causal-Functional Framework of System Variables*



Notes: The framework for this causal-functional analysis was adapted from Wiek et al., (2008). FV=focus variables, CV=context variables; FV*=future projections of focus variables, CV*=future projections of context variables; TV=target variables; AV=action variables.

Strategic Flexibility Analysis

The Strategic Flexibility Framework is a scenario analysis tool and its use in this study is based on the idea that Agricultural Educators and Human Resource Development professionals require flexibility to adjust decisions within given constraints. Strategic uncertainty that is associated with identification of future skill needs for emerging agrifood nanotechnology requires strategic flexibility and the ability to change strategies (Malik, Yawson, & Hensel, 2009a-b). Agricultural educators and human resource development professionals in the agrifood system risk arbitrarily narrowing their options of meeting the challenge of developing the human resources equipped with the requisite agrifood nanoskills if they attempt to base how the workforce should be developed on a precisely predicted skill requirements alone. This could prevent the consideration of a broader range of future possibilities. Agricultural educators and human resource development professionals need a range of future possibilities and corresponding strategy choices in tailoring their activities, rather than one strategy based on a declared vision of certain future skill requirements (Malik *et al*., 2009 a-b). The 'known unknowns' are also very important.

SFA is a four-step framework, defined by Michael Raynor in his book *The Strategy Paradox*: *Why Committing to Success Leads to Failure (and what to do about it)*. The relevance and justification of the use of SFF in this study is to identify as quickly as possible the agrifood nanoskill needs that are unambiguous, while maintaining as much flexibility as possible in describing skills that are unclear due to the emerging nature of nanotechnology. The implementation steps are Anticipation, Accumulation, Formulation, and Operation as described in the literature review section of this dissertation. In this study, the analysis was adapted and drawn substantially from the analytical approach developed by Deloitte LLC and described and used by Malik, Yawson and Hensel (2009). However, while we (Malik, Yawson and Hensel) used it for anticipated investment portfolios in emerging technologies, in this study it is used for anticipated skill needs and the educational policy and programmatic interventions.

I started the process by defining the drivers that are shaping the agrifood nanoskill needs as obtained from the multicriteria value elicitation and also from the SER. These drivers of change are what I have already described as context variables for the impact analysis (See Table 10). Once I described these drivers, I developed scenarios that provide “stories” about possible future realities (Malik et al., 2009a-b) based mostly on the qualitative expert elicitation. The next step was the creation of optimal strategies for each scenario based on experts’ opinions. I also identified the educational policies and programs needed to attain a given scenario. Different programs and interventions were then categorized as either core or contingent.

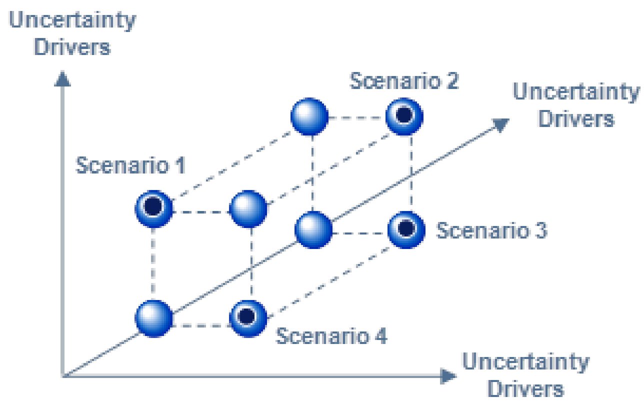
Subsequent steps of the SFA which were not included in this study due to limitations of time and scope, includes comparative analyses of educational policy reforms & interventions on the current trajectory with those chosen for each optimal strategy; detailed definitions of each optimal strategy along with descriptions of the types of risk associated with each educational policy reform & intervention; launching educational policy reform & intervention analyses; and, the construction of educational policy reforms & interventions portfolio.

Scenarios

Four scenarios were developed based on experts and stakeholder responses to key qualitative elicitations questions (See the Qualitative Elicitation Instrument: questions 1 - 5 in Appendix B). These scenarios are statements of how nanotechnology could shape the entire agrifood system and the logical consequence for new skills requirements. Each scenario attempted to identify the extreme limits of one of the drivers. This step is important because the insights gained by the process provides guidance to agricultural educators and HRD professionals to define the degree of flexibility in designing the necessary educational programs for agrifood nanotechnology workforce development.

Figure 30 is the graphical depiction of the scenario construction and the interrelationships. It also gives an indication that the scenarios developed in this study are not exhaustive and several other scenarios can be created. Drivers of change are defined to fully capture uncertainty along several dimensions (Malik et al., 2009b) as shown in the diagrammatic representation.

Figure 30. *Creating Scenarios*



Notes: Adapted from M. R. Malik et al., (2009)

Scenario 1: The World of Omics, Ology et al. – Rapid nanotechnology innovation dominates. This scenario is shaped by rapid nanotechnology breakthroughs and innovations in agrifood systems, along with significant product development that will have direct impact on skills needs and workforce development. Some of the products and applications expected to affect the agrifood industry in this scenario include all the typologies described as Focus Variables under the QSA (See Table 9).

> Food and agricultural workers will increasingly be exposed to nanotechnology and thus, new management practices, and development and production distributed over multiple countries and carried out by people from multiple cultures. Such new work circumstances call for skills not traditionally taught in school: communications, working in teams, problem-solving, and so on. An Experts Opinion (See Appendix A)

Economic and food consumption growth rates, along with population growth in emerging economies spur demand for agrifood products (Malik et al., 2009a). This creates a need for agrifood nanotechnology innovations and products. This need is complemented by demographic changes. The graying of the population in industrialized economies reduces the number of professionals involved in farming and animal production. Urbanization and industrialization in emerging economies reduce the human resources allocated to farming and production. These demographic trends fuel demand for increasing production efficiencies through nanotechnology innovations and for innovative agrifood products and thus the need for nanoskilled workforce.

> The future of agrifood nanotechnology depends in large part on the development of an efficient and productive research and innovation infrastructure based on interdisciplinarity. It requires as an input collaborative research from several fields of sciences such as: biological sciences, physics, chemistry, electronic, engineering, mathematics, environmental and safety related disciplines, cognitive sciences, social sciences, etc.
>
> An Experts Opinion (See Appendix A)

Scenario 2: Rifkin meets Bridges on the future of work in agrifood nanotechnology. Continuous announcements of nanotechnology developments give an indication of the future of work in the agrifood industry. Developments in nanotechnology are likely to revolutionize the agrifood industry. “The impact of such research and development upon skills development for employability—both in-school and at the workplace—is likely to be phenomenal” (Maclean & Ordonez, 2007, p.126).

There is no shortage of descriptions of the future of work in the literature, however, in this scenario, I focused on two very opposing future scenarios: Jeremy Rifkin (1994) *The End of Work* and William Bridges (1995) *JobShift*. These opposing viewpoints each have substantial repercussions for the future of agrifood nanotechnology workforce. This scenario is driven by marrying Rifkinian view that any hope that the high-technology *knowledge sector* will create as many new jobs as are destroyed is futile, with Bridges’ view that technology rather than eliminating job opportunities, will re-locate them. By marrying these two conflicting scenarios technology evolves as common driving force. On a spectrum, either nanotechnology will create new jobs and transform existing work to higher skill levels, or nanotechnology will destroy jobs or degrade them into less skilled, more routine work (Maclean & Ordonez, 2007).

Scenario 3: The World is One Flat World – A System of Connected Sub-Systems: This scenario describes the world as one system and it is predicated on Thomas Friedman's explanation of how the flattening of the world happened at the dawn of the twenty-first century(Friedman, 2005). Worldwide, trade, natural resources, and talent are each composed of interdependent sub-systems and the world is interconnected and complex networks of sub-systems that have both unique and common features (Malik et al., 2009b). One prediction in this scenario is that as agrifood nanotechnology companies continue to become more global, the R&D function will gradually spread throughout the world. Teams will function through electronic networks and management of the R&D function could be directed from remote locations, and therefore, how do you prepare the workforce to be localized global citizens? What skills are needed?

> Because of ICT, nanotechnology, globalization, and other competitive forces, have all combine to alter how work gets done. We are now a more "flatter" organization with less hierarchy and lighter supervision where workers experience greater autonomy and personal responsibility for the work they do than just a decade ago. Work also has become much more collaborative, with self-managing work teams increasingly responsible for tackling major projects. An Industry Expert's Opinion (See Appendix A)

Globally negotiated ranges of policies, standards, and regulations will govern the production, trade, health and safety, and environmental sustainability of agrifood nanoproducts and this will have direct implications on nanoskills requirements. Moreover, as nanotechnology becomes even more powerful driver globally, and national environmental challenges and regulations diminish in relative weight, skills needs will become increasingly even across countries and nanoskills will become less country-specific than they are at present (Strietska-Ilina, Hofmann, Haro, & Jeon, 2011). This means that changes in demand for, and in the content of, skills in the agrifood sector in other countries can inform policy decisions and training responses in here in the United States. There will thus be a need for more information on core, changing and emerging occupations and their skills content at a global level (Strietska-Ilina et al., 2011).

Scenario 4: The Education Pipeline Leaks – There are precedents and antecedents. There is no doubt that the United States leads the world in scientific and technological innovations and probably one of the worst K -12 STEM education in the leading industrialized countries (Goodstein, 1993). There is very little debate that both of these apparently contradictory assertions are true. Scientists, trained in United States graduate schools produced more Nobel Prizes, more scientific citations, more of just about anything you care to measure than any other country in the world; possibly more than the rest of the world combined (Goodstein, 1993). Consistently, the National Center for Education Statistics, for example, has found that educational attainment (as measured by upper secondary and university completion) in the United States as the highest among all G-8 nations. Yet, students in U.S. lower secondary and below consistently rank at the bottom of all those from the leading advanced nations in tests of scientific knowledge (Goodstein, 1993). However:

> A key challenge for nanotechnology development is the education and training of a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress of the new technology. …Such education and training must be introduced at all levels, from kindergarten to continuing education, from scientists to nontechnical audiences that may decide the use of technology and its funding. (Roco, 2002, pp. 1247-1248)

This scenario is therefore, based on the logical consequences of the paradox described. Due to the excellent nature of United States higher education system and the focus on advances and innovation in nanotechnology at that level, with the apparent neglect of CTE and also the continuous poor showing in STEM education at K-12 level, a future skill gap may be created. The United States will continue to lead the world with innovations but all the manufacturing and the related applications will be done elsewhere. There is a precedent and antecedent to this: The shipping of IT jobs overseas can be attributed to several reasons, but one key reason is that the middle level technical workforce are not available as compared to India and China.

> CTE should be a main part of any nanotechnology driven educational reform. However, if CTE is to have a role in successfully preparing agrifood nanotechnology workforce, a look at program content, how to deliver CTE programs, and let go of what no longer works. The dichotomous silos of academics versus CTE must be eliminated and their supporting infrastructures must be re-imagined to meet the needs of the economy. As result of blurring of disciplines with the emergence of nanotechnology, so too must the lines that currently separate GE and academic education.
>
> An Industry Expert's Opinion (See Appendix A)

There is therefore the need to seal all the leaks in the educational pipeline and CTE should be a main part of any nanotechnology driven educational reform. However, I must add that not all experts agreed to the role of CTE. "Technology development should be done in 4 year Universities rather than vocational venues because the technology requires expansive skills development only acquired in 4 year school and graduate work". An Academia Expert's Opinion (See Appendix A)

Choosing strategies

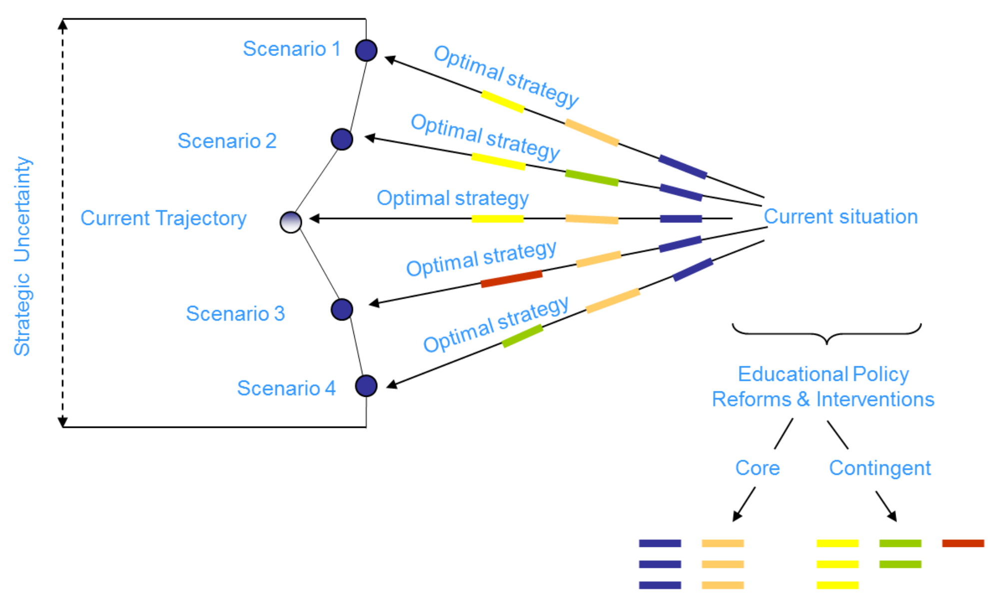
Choosing strategies representing the full range of strategic uncertainty relevant to the agrifood industry were obtained from the SER. These were then formulated into questions as part of the expert elicitation. Please see the details of all the strategies as presented in *Part IV – Impact on Skills* section of the quantitative expert elicitation questionnaire. (See Appendix B).

Identifying optimal strategies

Identifying optimal strategies relevant to the agrifood industry were obtained by responses of experts to several elicitation questions including: the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in nanotechnology; measure(s) agrifood businesses should take now to address skill needs; what should be improved within the higher education system to better fulfill skill needs related to developments in nanotechnology; and, what should be improved within the vocational education and training/Career and Technical Education system to better fulfill skill needs related to developments in nanotechnology. Please see Figures 14, 15, 17 and 19 for expert responses.

Figure 31 shows graphical representation of identifying the optimal strategies and educational policy reforms and interventions.

Figure 31. *Graphical Representation of Identifying the Optimal Strategies*



Systems Dynamics Modeling

The final phase of the analysis which is the 4th Phase of the study is development of a generic agrifood nanoskills systems dynamics model from the analytical results of the multicriteria elicitation, and the systematic evidence review. The model presented is centered on three basic state variables or stocks: *Agrifood NanoSkills Gap (Skills Gap)*; *Agrifood Nanotechnology Workforce Base (ANWB)*; and *Agrifood Nanotechnology Education (ANE*). Stocks represent the accumulations in a system. The entire systems model as presented gives visual access to systemic interdependencies between nanoskill requirements, training, curriculum design, human resources and workforce developments and allow for feedback loops among these different typologies.

The dynamic behavior of the model is partly specified by the integration process (implicit delays) on these three main stocks as well as the various assumptions plainly defining behavioral reaction and the delays put down in smooth- as well as delay-functions (Nielsen & Nielsen, 2006). The dynamics for the three stocks are given by their respective rate-inflow and rate- outflow functions.

Stock/Flow (S/F) Maps

Stocks represent the accumulations in a system. The multiple factors that may be influencing the flows and contributing to the feedbacks that control the system's behavior can be better understood by graphically representing the stocks and flows and their relationships (CFSD, 2003).

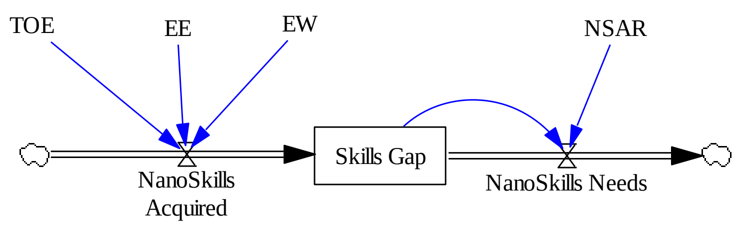
- Dynamics of the stock variable "Skills Gap":

Skills Gap	=	INTEG (NanoSkills Acquired - NanoSkills Needs)
NanoSkills Acquired	=	EE*EW*TOE

NanoSkills Needs = Skills Gap*NSAR

The "NanoSkills Acquired" rate of change (flow) variable is modelled as the product of the variable "Employable Workforce (EW)" with an "Effective Education" coefficient (EE) and a coefficient indicating "the type of education" per time unit (TOE). The "NanoSkills Needs" rate of change variable is modelled simply as an exponential decay mechanism with the decay rate i.e. nanoskills acquisition rate (NSAR) per time unit. Figure 32 shows the stock/flow map of skills gap which has been identified as a key programmatic intervention point.

Figure 32. *The Stock/Flow Map of Skills Gap*



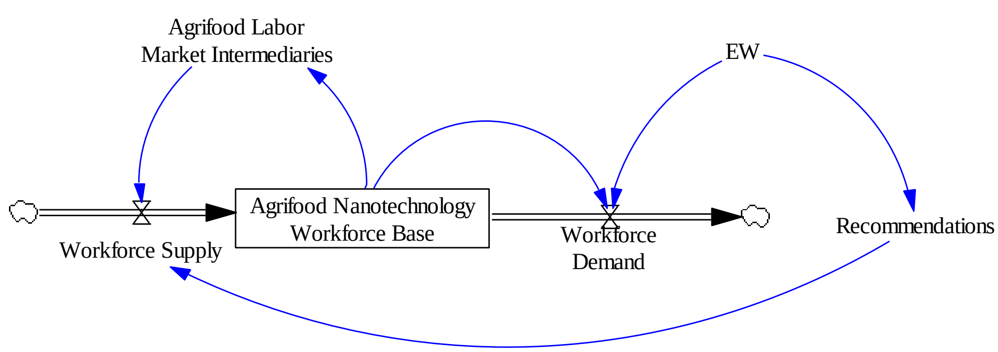
- Dynamics of the stock variable "Agrifood Nanotechnology Workforce Base" (ANWB):

ANWB = INTEG (Workforce Supply - Workforce Demand)
Workforce Supply = IF THEN ELSE (R+2>0, ANWB*(R+2), 0)
Workforce Demand = IF THEN ELSE (EW<0,-0.1* ANWB *EW, 0)

The "Workforce Supply" rate of change variable is modelled as a function of some index measuring ("Recommendations"+2) (R) per time unit so that if R>0 then "Workforce Demand" = "ANWB" multiplied by "Recommendations" (R) and else zero. The constant value of 2 added to the "Recommendations" accounts for the fact that if

"Recommendations" equal zero there are still a flow of workers into the Agrifood Nanotechnology Workforce base from Agrifood Labor Market Intermediaries (LMI). The "Workforce Demand" rate of change variable is modelled in a similar manner as a function of some index variable "Employable Workforce" (EW) per time unit and the mechanism is only active if EW<0 where it is given by "-0.1* ANWB*EW" that is in fact a positive workforce demand and zero else. Figure 33 is the stock and flow map for agrifood nanotechnology workforce base

Figure 33. *Stock/Flow Map for Agrifood Nanotechnology Workforce Base*



- Dynamics of the stock variable "Agrifood Nanotechnology Education (ANE)":

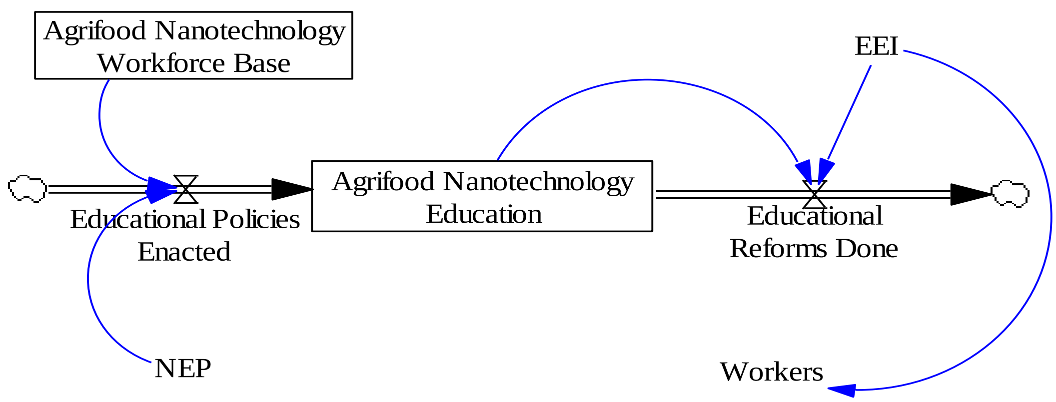
ANE = INTEG (Educational Policies Enacted – Educational Reforms Done)

Educational Policies Enacted = NEP*ANWB

Educational Reforms Done = MIN (ANE, EEI*Workers)

The "Educational Policies Enacted" rate of change variable is modelled as the product between the "Number of Educational Policies Enacted" (NEP) per time unit and the "Agrifood Nanotechnology Workforce Base". The "Educational Reforms Done" rate of change variable is modelled as a minimum function between the variables "Agrifood Nanotechnology Education (ANE) and an Educational Infrastructure Capacity Constraint given by multiplying the "Existing Educational Infrastructure" (EEI) per time unit and the number of workers in the agrifood nanotechnology workforce (Workers). Figure 34 is the stock and flow map for agrifood nanotechnology education another key programmatic intervention point

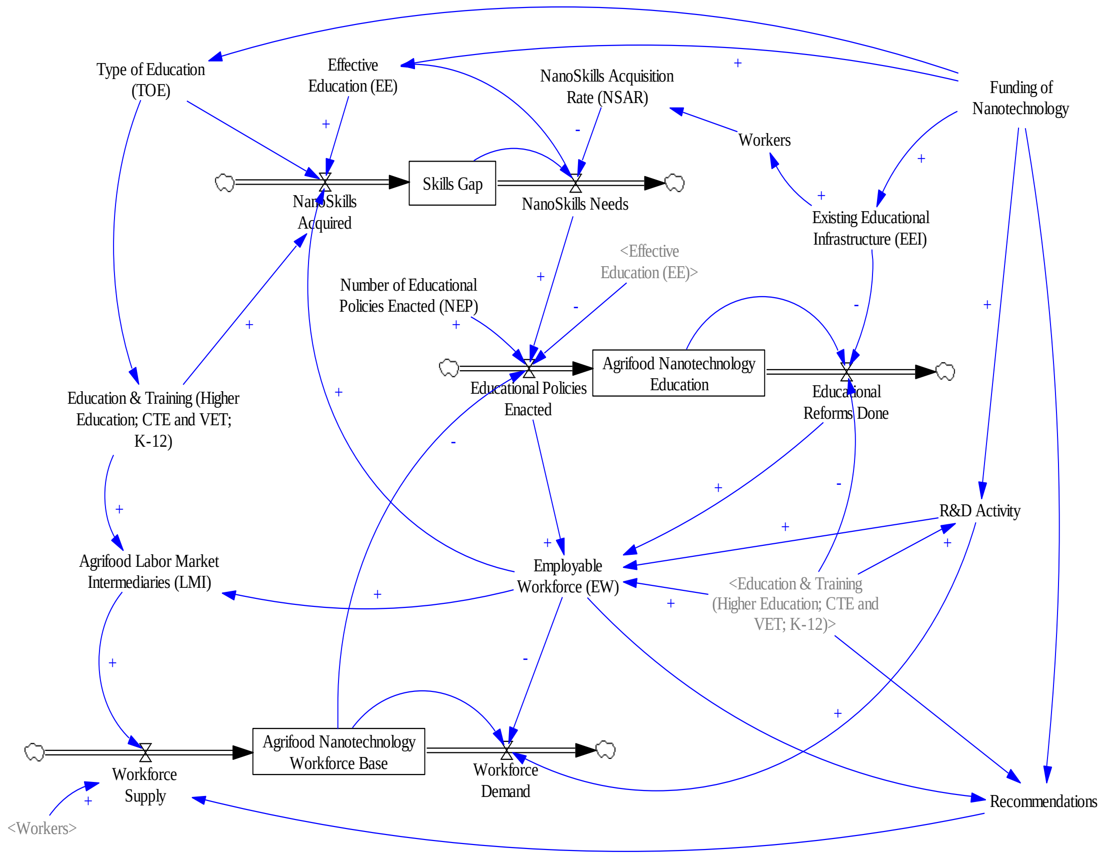
Figure 34. *Stock/Flow Map of Agrifood Nanoeducation*



Behavior-Over-Time Graphs (BOTGs)

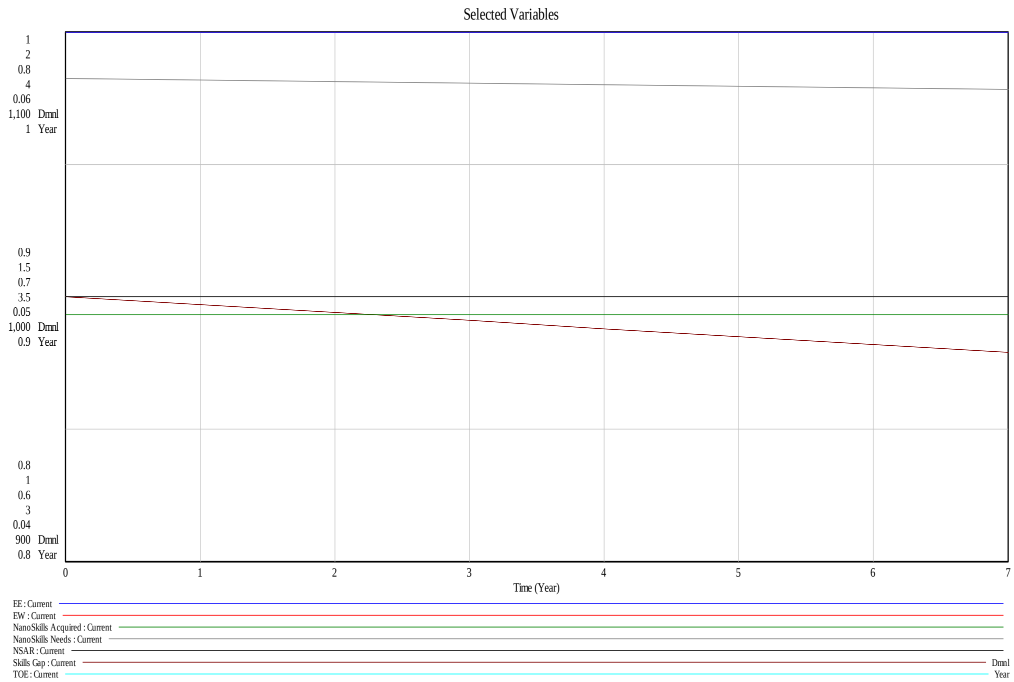
A BOTG, consisting of a line graph with time on the X-axis, captures one of the most fundamental aspects of this study. The focus here is on patterns of change anticipated for agrifood nanoskill requirements over time. In order to assign calendar time dimension in addition to the time units, I placed the coefficients as well as functional relations in proper sizes relative to a desired time frame of 7 years. I chose 7 years because most of the projections in the literature are made with the year 2020 as the projected date which is 7 years from now. Figure 35 shows the overall systems map.

Figure 35. *Agrifood Nanoskills Systems Model*



In essence, the coefficients which must have the time dimension given by definition are, "Type of Education (TOE)" = 1 per year (per worker); "Nanoskills Acquisition Rate (NSAR)" = 0.05 per year; "Number of Educational Policies Enacted (NEP)" = 2 per year. I situated the model in time units equal to years. The actual settings for the variables TOE, NSAR and OF used are completely arbitrary and principally for illustrative determinations, as is the model structure in general. I consciously selected very simple functional relations, primarily to make a generic point of argument.

Figure 36. *Behavior Over Time Graph for Skills Needs*



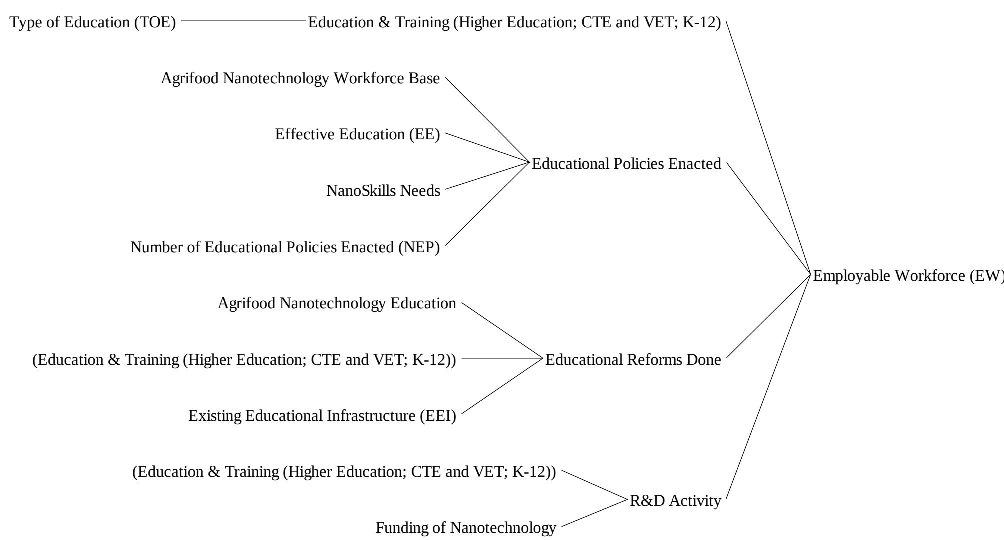
This type of generic System Dynamics model setup as presented in this study has also been used by numerous authors (e.g. Nielsen & Nielsen, 2006; Sterman 1997; Schöneborn, 2003). In order to get a very dynamic model, the functional assumptions that determine the behavior of the following variables EE, R, EW and EEI should be described based on the setting the model is used, be it regional, federal, a firm, college, department etc.

Although I have not created any scenario for simulation, just by the logical structure of the model, a behavior over time graph for stock variable “Skills Gaps” can be generated as shown in Figure 36. The BOTG shows that if all the other variables shown in the map remain constant, Skills Gaps will be reducing. This is explicitly for illustrative purposes and does not validate the model in anyway. The model as it stands is generic, which can be adapted, refined and validated empirically through further research.

Causal Loop Diagrams (CLDs)

CLDs obtain from this modeling exercise depicts the behavior of critical elements of the agrifood system impacting skill needs and also provide understanding and communicating the interactions that determine those dynamics.

Figure 37. Causes Tree Diagram for Employable Workforce



For this model 20 key causal loops were generated. See Appendix F for the list of causal loops. The various functional relations are also presented in Appendix F. Causes Tree and Uses Tree diagrams are also very important in understanding the model structure (R. M. Yawson & Kuzma, 2010a) For example a causal tree diagram for "Employable Workforce" generated from the model is as shown in Figure 37. The causes and uses trees are used to breakdown wide systems map into finer levels of detail for particular variable of interest.

Chapter 6 - Conclusions and Recommendations

In this last chapter of the dissertation I draw conclusions about the impact of nanotechnology on current and future employability skills and competences needed in the agrifood sector and the required policies and programmatic intervention points that may serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the sector. I also present recommendations on education, training and other measures to be implemented to fill potential employability skill gaps. The study set out to answer the following question: ***What are the future skill needs in agrifood nanotechnology?*** The study also addressed the following related questions:

1. Who are the stakeholders in agrifood nanotechnology workforce development and how do they perceive skills shortages and gaps in the sector?
2. Based on an understanding of skill shortages and gaps, how can educational practice and policy meet these needs?
3. What policies and programmatic intervention points can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector?

Agrifood and Nanotechnology

Although agrifood and nanotechnology are sectors with a strong global character, this study confined itself to the United States, notwithstanding, the applications of the findings may be transferable to other regions. The first striking observation was the newness of the term ‘agrifood’ to many of the stakeholders interviewed. Although, the use of the word has been around since the 1980s, I realized that it is not a popular term in the United States, as it is in Europe, Australia and Canada. However, the term was not new to the experts. Another critical observation is the level of nanoliteracy(R. M. Yawson, 2012); knowledge level of key stakeholders were very low. For example, out of the 72 participants from the AHRD, 60 responded to the question “what is the level of your knowledge of Nanotechnology?” and out of this 60 respondents, 40% indicated on a Likert scale of: Very Knowledgeable; Knowledgeable; Somewhat Knowledgeable; Not Very Knowledgeable; and, Not at All Knowledgeable, that they are ‘not at all knowledgeable’ and 38 percent indicated ‘not very knowledgeable’. Similarly, of the 66 respondents out of the 70 participants from AAAE, 29 percent said ‘not at all knowledgeable’ and 50 percent indicated that they are ‘not very knowledgeable’. This made this study not an easy task. Furthermore, because of the limited number of interviews that could be performed, the study has a somewhat explorative character especially where it concerns the strategic flexibility analysis and the systems model.

The level of nanoliteracy also poses a serious challenge to the development of nanotechnology in general. These stakeholders are critical to the development of the future workforce in agrifood nanotechnology and therefore it is important that they become aware of what is happening in the field. Agricultural Educators and professionals must appreciate the impact nanotechnology will have on the agrifood sector, appreciate what is needed to prepare the agrifood nanotechnology workforce, and successfully translate that to students and parents (R. M. Yawson, 2010). Administrators and academic staff must be ready and take the required process to make the transition in a new technology paradigm. The role of industry, NGOs, government and the public itself cannot be discounted in this process. All factors that contribute to a technological literate population, prepares people for work or offers them an opportunity to improve their skills forms part of the workforce education system (R. M. Yawson, 2010).

Skills Needs, Shortages and Gaps

Both the SER and the multicriteria value elicitation indicate that employment increases related to nanotechnology developments in the agrifood sector are expected, although most of the evidence from the SER is anecdotal. There were differences in expert opinions about the pace and importance of changes that nanotechnology will have on agrifood and its impacts on skills. These underscore the importance of the strategic flexibility analysis done in this study. Due to the emerging nature of nanotechnology and especially in agrifood, there is some uncertainty and ambiguity about the implications for human resources. However, there are some trends to be distinguished from this study. The most important one is that both skill shortages and skill gaps will increase if we continue on our current trajectory.

Ultimately, the systematic evidence review of the literature answered the main research question "What are the future employability skill shortages and gaps in agrifood nanotechnology?" as follows:

- There is a significant lack of data in the literature to fully answer the main research question and there is almost nothing written on the skills needs specifically for agrifood nanotechnology. For nanotechnology in general, there is also no reliable data available to do any comparative data analysis. These difficulties have the latency to facade specific, critical problems and also blur understanding of the actual skills requirements.

- Several conceptual articles indicated that current high level skills needs in the agrifood sector can be met with existing supply, but due to the emerging nature of the applications of nanotechnology in the agrifood sector there is very little reliable data exploring the future demand for agrifood nanoskills and therefore difficult to predict the future skill needs.
- That employability skills will be more important and will be needed in the future and that is where the future shortages may arise. From the SER, it is clear that all the 39 employability (general) skills listed in this paper will be needed. All technical skills listed in this study and used for the expert elicitation will also be important depending on the specific area in the agrifood sector, but as experts noted, it is easier to equip students with technical skills related to a particular technologys by the educational system, than it is to develop employability skills. Moreover, as the technology emerges technical skills also emerges and the educational system is able to meet the challenge.
- There are some particular areas of concern in the very high skill levels needed to support the R&D base and the future needs of agrifood nanotechnology research and therefore interdisciplinary skill sets should be important. Students in the agrifood programs should be exposed to advances in nanotechnology. Almost every single article used for the final evidence review mentioned the importance of interdisciplinary and multidisciplinary competency and training.

From the multicriteria elicitation, the results of the SER evidence is more or less confirmed. When experts were asked whether nanotechnology will create skills gap and shortages in the agrifood sector, 44% indicated that there will be substantial skill gaps and 39% indicated that there will be limited skill gaps. Majority of all the various stakeholders and stakeholder groups also believed that there will be substantial skill gaps. From the ranking analysis of employability skills by experts and stakeholders, almost all the 39 employability skills and competencies had an average rating above 3 on the Likert scale of 1- 5 with 5 being the most needed. See Figures 10, 21-25, and Appendix D for details of the ranking. Employability skills and competencies like: Problem-solving and critical thinking; New Product Innovation; Nano info, products, industry; Research and Development Management; Environmental and Sustainability; Lab equipment, instruments, analysis; Ethics; Risk Assessment and Management; and Chemistry, physics, materials science, were highly ranked. The 5 industries/businesses surveyed ranked all the skills 4 or 5. Experts and stakeholders were given the opportunity to identify other skills and competencies not among the list obtained from literature and nothing was added. The importance of employability skills were stressed on by several experts interviewed

> Employers are not too worried about the skill needs and even when they did, the theme of what we heard was actually much more generalized than technical. You know, what we heard over and over was that people need to be interdisciplinary. They need to have knowledge from a variety of different areas but the employers didn't naturally start talking about particular technical skills that they needed, the message was a bit more generalized skills. An Expert Opinion (See Appendix A)

Similarly Experts were asked to select from 44 technical knowledge competencies identified in the literature which ones they would like delivered from nanoscience and nanotechnology education for placement in agrifood nanotechnology sector and all the 44 technical knowledge competencies were seen as important with the knowledge in Chemistry; Nano - biology interfaces; Material Science; Microscopy; New materials, properties and their selection; Technical communication (Written and spoken);

and, Health and Safety, being the most highly ranked. See Figure 11 for details of the ranking. Similar results were also obtained with regards to industry and education stakeholders' surveys. The classifications used for both employability and technical skills sets were based on SER.

Agrifood Nanotechnology Education and Training

One important issue that came out from the surveys and interviews is the extent to which students in higher education (BS, MS) should specialize in nanotechnology as a field. Most of the experts indicated that less specialization within science, but more general knowledge of scientific domains within science should be the way forward for nanotechnology developments. However, some of the experts indicated that the example of State University of New York system where there are specialization in nanotechnology and students graduate with graduate and undergraduate degrees in nanotechnology is a good model, because the students are trained specifically for available jobs in the region with direct input from the industry. The alternative for such specializations would be more generic scientific education, in combination with on the job training in companies for new employees. The interviews and survey with industry/businesses show that they prefer that students are taught in the basic disciplines – i.e. have a more general profile - and do not specialize too much.

On the whole there was an overwhelming agreement that, to a great extent the higher education system (universities, polytechnics, higher vocational education) in the United States will be able to fulfill skill needs related to present and future developments in nanotechnology. See Figure 16 for details of the quantitative responses. However, almost an equal number of Experts indicated that stronger cooperation with companies and effective academia-industry-government partnership is needed to improve within the higher education system to better fulfill skill needs related to developments in nanotechnology

Experts also stressed the importance of K-12 education and VET/CTE and indicated that future skills gap and shortages may not be because of lack of ability of Higher Education to develop the required number of students with needed employability skills, but rather will stem from “leaks’ in the educational pipeline as described in the scenario 4 of the SFA. One of the causes of future skills gaps and shortages will be the decreasing interest of K-12 pupils in STEM. The SER shows that in all sectors there is large concern about the shortage of higher education STEM graduates especially in the face of global talent pull. Most experts recommended the National Science Foundation’s Initiative on K-12 Nanotechnology Education and stressed the importance of making it a seamless part of the broader STEM education.

With regards to CTE/VET, the majority of the experts think that ‘somewhat’ the CTE/VET system in the United States will be able to fulfill skill needs related to present and future developments in nanotechnology. See Figure 18 for the quantitative responses. Most the experts’ interviewed thought that current programs within the two-year technical colleges are good, but the number of the colleges involved may not meet the future workforce demand. As to what should be improved within the VET/CTE system to better fulfill skill needs in the agrifood sector related to developments in nanotechnology, quantitatively majority of the experts indicated stronger collaboration with industry. See Figure 19 for the quantitative response. All but one of the Education

Institutions that responded to the survey indicated that they expect the role of nanotechnology in the education programs of their faculty/ department to increase in the next five academic years.

Collaboration between Key Stakeholders

In an attempt to answer the related research question of who the stakeholders in agrifood nanotechnology workforce development are, and their perception of skills shortages and gaps in the sector, interesting results were obtained. Experts identified large scale agrifood companies; government agencies (FDA, USDA, EPA etc.); institutions with nanotechnology workforce development; and, users of agrifood products, as the most important stakeholders in that order. Several stakeholders identified through the SER were also highly ranked. However, Experts did not find the Judiciary and School Boards as important stakeholders although in the literature school boards were identified as important stakeholders.

Both the SER and the multicriteria value elicitation clearly showed that collaboration between stakeholders especially for curriculum development is important. An important aspect of this study is the development and use of stakeholder analysis methodology and how it can be used to develop effective collaborations. Collaboration is an important programmatic intervention that can serve as leverage point for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector. There should therefore be an intentionality among all the stakeholders about collaboration.

However, findings from this study shows a strong discrepancy in how industry and academia see collaboration with regards to the mutual cooperation and alignment of workforce development. The majority of the Education Institutions surveyed indicated strong collaboration with industry. However, the story is quite different from the perspectives of industry. Although industry stakeholders surveyed and interviewed mentioned stronger collaboration and partnership between Industry and Academia as the most important option for improvement of both the higher education system, as well as the VET/CTE system, the general perception is that academia does not really show any commitment to the collaboration unless in cases where industry funding is involved, which in most cases for research and not necessarily for curriculum development.

Evidence from the literature shows that the main barrier militating against the effective collaboration between industry and academia is that the interests and incentives of industry and academia in such collaborations are very different (Gelderblom et al., 2012). A key example from the literature is the importance of interdisciplinarity with regards to innovation in industry; whereas in academia, education and research mainly take place within disciplinary boundaries, although this is gradually changing because of the requirements of funding agencies. In addition, “university researchers are driven by incentives like reputation and publications (and interdisciplinary journals have relatively less high impact scores), which differ from companies (royalties, propriety patents)” (Gelderblom et al., 2012). There also an apparent tension between all-embracing industry engagement and the traditional role of universities which is based on the pursuit of knowledge (Allen Consulting Group, 2012). Too much industry focus has the tendency of branding degrees not as academic degrees but vocational degrees. This argument may not stand the test of rigor, considering the preponderance of evidence suggesting that many professional qualifications offered by universities where the curricula were developed with heavy input of industry and professional requirements are often, among the highest employment outcomes and also score strongly in graduate ratings of course relevance (Allen Consulting Group, 2012).

Policies and Programmatic Intervention Points

The strategic flexibility analysis of the results of this study and the generic systems model developed bring out the important policies and programmatic intervention points that can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector. To avoid future skill shortages, there will be the need to devise strategies based on well-informed policy decisions. Labor market information, anticipation of skill needs for agrifood nanotechnology, and the continuous translation of indicators of the labor market intermediaries (LMIs), as depicted in the systems model, into updated training provision are needed to become integral elements of such strategies.

The broad scheme for dynamism of systems and the results of this study would perhaps provide some leads and ideas for future study to fill data gaps. Although the goal of the model was not the accurate quantitative estimation of forecasting for future skill needs in agrifood nanotechnology, it enhances the understanding of the mechanism of skill needs identification in agrifood nanotechnology as a system. The model can be adapted to suit several purposes including curriculum development, educational policy formulation, skill needs identification and related issues to properly understand the interrelationships and what may be unintended consequences of policy implementation.

Interdisciplinarity of nanotechnology was a recurring issue in the multicriteria value elicitation and the SER. It is my contention that interdisciplinarity in the context of nanotechnology is more than knowledge exchange between different well-defined disciplines; instead, disciplinary boundaries should be constantly redrawn and renegotiated during the process of exchange based on various stakeholder interests. However, skills should not be seen as mere servant of the economy, solely reactive in the face of change. “Every policy can tap the power of skills to promote change, if skills are considered an important function of the planning and implementation processes” (Strietska-Ilina et al., 2011. p. 162). Framing interdisciplinary skills in nanotechnology as a sociopolitical boundary-making process may clarify training issues in Nanoeducation (Tsai-hsuan Ku, 2012). Stakeholder interest in describing nanotechnology as interdisciplinary and the ensuing requirement for the acquisition of interdisciplinary skills can be daunting. Some of the industry/business experts interviewed for example framed this problem as one of ‘a shortage of nanoskilled workforce’, but the process of developing interdisciplinary nanoskilled employees have been proven to require “carefully designed organizations to establish a disciplinary order capable of focusing resources, knowledge, and labor to bear on specific problems without being diverted by diverse interests” (Tsai-hsuan Ku, 2012, p. 376).

Recommendations

Several recommendations can be gleaned from the findings of this study and the following are some of the key programmatic intervention points that serve as my recommendations:

- Agricultural educators and human resource development professionals in the agrifood system risk arbitrarily narrowing their options of meeting the challenge of developing the human resources equipped with the requisite agrifood nanoskills if they attempt to base how the workforce should be developed on a precisely predicted skill requirements alone. This could prevent the consideration of a broader range of future possibilities. Agricultural educators and HRD professionals need a range of future possibilities and corresponding strategy choices in tailoring their activities, rather than one strategy based on a declared vision of certain future skill requirements. The strategic flexibility analysis done in this steady can serve as an important primer for addressing these broad range of future possibilities.
- Increased engagement between all stakeholders in the agrifood sector especially Government, Technical/Community colleges, Universities and Business/Industry in relation to the content, design and delivery of educational program (so curriculum and training throughout the workforce development pipeline can adequately meets the needs of the sector). It is important to conduct proper stakeholder analysis to be able derive proper presentation. The analysis done in this study is an important first step that can be replicated.
- Employers will hire qualified students wherever they are. If agricultural educators fail to align their curriculum with the skill needs of agrifood industries in the wake of the emergence of nanotechnology, companies that traditionally employ graduates from colleges of food and agriculture may look elsewhere in the universities and colleges and may find better qualified students in other

colleges throughout the university as a result of the trans-, inter- and multidisciplinary nature of nanotechnology. Due cognizance should be given to changing the foundation of learning in colleges of food and agriculture, beginning with broader concepts of nature, and converging platforms in the freshman year, instead of beginning with introductions to narrow disciplines (Roco, Bainbridge, Tonn, & Whitesides, 2013).

- "Any curricula developed for agrifood nanotechnology should be based on good theoretical foundations and a balance of knowledge competencies drawn from mathematics and the physical sciences together with the chemical and biological sciences integrated with applied sciences, commerce, management, social sciences and the humanities". (Yawson, 2010, p 290)
- It is important that industry play an active role in the provision of leadership to address agrifood nanotechnology workforce and skills development related issues, most importantly by working closely with academia and government stakeholders to develop and drive the implementation of unified and enduring solutions to agrifood nanotechnology workforce and skills needs.
- Nanotechnology should be incorporated into all aspects of K-12 STEM education programs and initiatives. From systems perspective, STEM education should not be devoid of the employability skills, or else there may be the unintended consequences of highly trained future STEM workforce with no employability skills.
- It is important to implement an initiative to identify existing public and private initiatives in each State that focus on addressing workforce development, skills

development, education and training issues in nanotechnology so as to identify best practices and also linkages or inconsistencies between existing initiatives to improve stakeholder awareness and understanding of, and accessibility to existing measures. This will help in sharing knowledge and learnings and best practice approaches to identify gaps and opportunities for future work or new initiatives and improve coordination and consultation between States in the implementation of agrifood nanotechnology workforce development programs.

Implications of study to HRD, AgEd, and Science Policy Research and Practice

As part of the preparation towards this study, I have in the past three years published 6 peer-reviewed journal articles directly in relation to this study and have been drawn substantially upon in this dissertation. I have also had the opportunity of attending and participating in conferences and workshops to share my thoughts and present papers related to several portions of this dissertation.

The outcomes of this dissertation as described herein and the potential impact of this research to my areas of specialization--public policy, human resource development, and agricultural education--will be far reaching. Important evidence needed to develop educational policies for agrifood nanotechnology workforce development are available from this study. In terms of contribution to knowledge, the methods and approaches for this research are drawn from existing and emerging methodologies within these disciplines in a mixed methods approach creating, in some of the disciplines, a novel research framework.

Recommendations for Sharing Research

As a result of the implications of study to HRD, AgEd, and Science Policy research and practice the following are recommendations on how the findings of this dissertation will be disseminated and shared:

There are three kinds of academic beneficiaries of the findings of this research: Researchers who are studying the emerging field of nanotechnology; administrators of academic institutions that are training researchers and practitioners and can use the research as a basis for student research and curriculum development; and future researchers and practitioners who can better prepare themselves to be effective in understanding and addressing skill needs and workforce development issues in emerging technologies.

The results and findings of this dissertation will be of value to a wide range of academic researchers who are concerned about the emerging field of nanotechnology and its impact on human resource and workforce development; agriculture and food; organizational development; and public policy. These diverse disciplines are eager to understand the growing influence of nanotechnology on human capital. The results and findings reported in this study give academics much-needed scholarship and data on which to build future inquiry. In addition, the use of the systems and complexity theories will be of interest to scholars who use this frame for understanding complex, systemic, and intractable issues such as workforce development for any emerging sociotechnical system.

The findings of this study will also be shared with some selected deans of colleges and chairs of department of food and agriculture. This will be done with some face-to-face meetings, electronic communication and publication in some popular media outlets. The proposed freshman year syllabus included as Appendix G of this dissertation will be a good candidate for sharing with Academic Institutions.

This research will also be disseminated through standard academic channels such as peer reviewed journal publications; and workshops and conferences. Specifically, the following academic channels are anticipated:

- "What is in a name? The identity crisis of Agricultural Education Departments: Is Agrifood the answer?" will be a spin-off to this study which will be shared with members of AAAE through presentation at the annual conference and/or through publication in the *Journal of Agricultural Education*.
- The results of the "qualitative system analysis as a means for skills needs identification: The case of agrifood nanotechnology" will be published in any of the leading nanotechnology policy journals.
- Results of the "systematic evidence review of skills needs identification for agrifood nanotechnology" will be published in *Human Resource Development Review* journal.
- "Strategic flexibility analysis of skills needs for agrifood nanotechnology" will be published in a public policy/ education journal
- "Systems model of policy and programmatic intervention points for agrifood nanotechnology workforce development" will be presented at the annual conference of the Systems Dynamics Society
- "Importance of mixed methods research approach to skills needs identification studies" will be presented at the Annual AHRD conference in the Americas

- “Agrifood nanotechnology workforce development: A stakeholder analysis” will be published in the Academy of Management Journal to disseminate as widely as possible the methodology developed for stakeholder analysis.

Limitations of Study

There are several limitations to this study which were mostly related to scope, time and resources. Most multiphase mixed method studies are conducted over a long period of time involving researchers from different disciplines (Creswell & Clark, 2011), as a result the study did not use the full compliments of these methods and approaches:

- First of all, the systematic review was exclusive to English language journals that are found in the main databases. Articles that do not cite the search terms in English, and journals that are not included in the main databases, were not captured or excluded from the analysis. In addition, the search in the main databases was not full, since it omitted books that are not online and unpublished conference proceedings with exception of those published in special editions of journals.
- Sample sizes and response rate of some of the key stakeholders were low although several measures were put in place to reduce response bias, it is easier when surveying a single population. Several of agrifood nanotechnology companies contacted refused to participate citing reasons of proprietary information. An example of some of the responses is: “Dear Robert Yawson, We received your survey and while we appreciate the interest in understanding …..'s

strategy, the information you seek is proprietary and therefore, we are unable to complete the survey" Similar emails were received from several firms.

- The full complement of the strategic flexibility analysis and systems dynamic modeling were not used. The full complement will have included a workshop for experts and stakeholders to discuss and do several iterations until a complete SFA is done and every parameter and variable in the systems model discussed. In any model such as presented in this study, where the inputs are mostly facts with some level of uncertainty, and experts' opinions with unknown values and functional forms, no quantitative conclusions can be drawn without experimental or further empirical research (R. M. Yawson & Kuzma, 2010a).

Recommendation for Future Research

This dissertation creates the need and a platform for further research. Generally, the findings from this study, specifically in relation to employability skills, are not explicit to agrifood nanotechnology. They are what can be broadly described as 21st century skills. There are however, specific technical competencies identified for nanotechnology and agrifood nanotechnology specifically. The recurring issue of interdisciplinary skills demands further research. The sociopolitical aspect of developing interdisciplinary skills/expertise in nanotechnology described earlier, raises the question of scientific accountability, the problem of how multidisciplinary boundary activities are warranted and evaluated. Current metrics evaluate 'final products' (numbers of papers, patents, citations, and human capital) and cannot capture the dynamics, content, and crucial 'practice' of realizing abstract concepts in an intentionally constructed social infrastructure (Tsai-hsuan Ku, 2012). This underscores the importance of systems and complexity theories underlying this study. There is the need for a collaborative study involving natural and social scientists in documenting and analyzing practices at different nanotechnology centers and businesses. These empirical studies can offer a basis for better judgments and realistic expectations in planning nanoscience policy and education.

As I have mentioned elsewhere in this dissertation, one of the interesting findings outside the main objective of this study or the research questions, was the newness of the term ‘Agrifood’ to most of the stakeholders and even some of the experts. Several members of the AAAE were intrigued by the term. This speaks to the current identity crises faced by several Agricultural Education Departments. It has been reported that one of the barriers to increased enrolment in agriculture related qualifications is the perceptions and understanding of the term 'agriculture' (Allen Consulting Group, 2012). Another, issue that creates the need for name change is how industry perceives the degrees from the Agricultural Education Departments and therefore appropriate placements and career pathways. A study to elicit the views of key stakeholders in the inclusion of the term agrifood in names of departments and colleges of agriculture to address the current “Identity Crises” is therefore recommended.

Although this study has yielded a number of important findings which have implications for policy and action, in-depth analysis of the skills requirements of agrifood nanotechnology and more focused thematic analyses, for example occupational profile analysis in agrifood nanotechnology and related competency profiles are still needed.

Multidisciplinary training for the future workforce in nanotechnology was a recurring theme and a major finding in this study. Multidisciplinary competency is increasingly required as tasks and industries converge and the development of solutions to new challenges requires systemic thinking. A multidisciplinary approach to training at all levels of education for nanotechnology is thus required. It is therefore important that a further study to empirically test the systems model developed be conducted.

Further to what has been recommended in the preceding paragraph, there is the need for an integrated education systems to support multidisciplinary training. The emerging nature of nanotechnology and the global economy require serious redesign of education, in K-18 education, college, the workplace, and adult and lifelong learning (M C Roco et al., 2013). The curriculum redesign should cater for flexible adaptation to change and integrated across disciplines and even getting ahead of trends, to transform education into an engine of creativity and innovation (M C Roco et al., 2013). An action research can be developed where incremental education redesign can be tested. Appendix G is a proposed syllabus that can be used in colleges of food and agriculture for the freshman year as a start to any such action research.

Future research emanating from this dissertation could include the application of the different methods and analytical tools used in this study for other research in Human Resource Development and Agricultural Education. One important aspect of this study is the introduction of SER as a research methodology in HRD and Agricultural Education. Although the full complement of SER as used mostly in medical intervention research was not used; the adaptation of the overall process in an HRD or AgEd research may serve as an important research approach. It is a research approach that can be refined and used in HRD or AgEd research and scholarship to complement or serve as alternative to integrated literature reviews and an obvious departure from the traditional narrative reviews (Yawson, 2013). The methodology developed for the stakeholder analysis can be developed further and used in HRD or AgEd research.

A lot has been written in the literature on the importance of Academia-Industry-Government collaboration and how important it is for innovation and human capital development. But as the results from this study indicate, there are very intractable and complex issues facing this collaboration and for collaboration to achieve desired goals. There is the need for a study to understand these complexities and the kind of leadership roles needed to make collaboration between Academia-Government-Industry-Third Sector-Public seamless.

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Appendix A - Qualitative Expert Elicitation

Table A1. *Qualitative Expert Elicitation – All Experts*

Question	Key Responses
What do you see as trends in the agrifood nanotechnology sector?	• Currently in use in packaging and sensors but data must be developed to reduce fear associated with nano in the environment and nano in food. • Stealth, primarily. The food industry is loath to advertise the use of any nanotechnology • IFR monitoring. Packaging for safety and inventory. Applications in fields like colorants and favorants. • food safety • Aside from relatively straightforward electronics and materials development, II don't think the sector is going anywhere fast. • Great excitement for application of nanotechnology - little consideration of environmental consequences • None until government makes a decision about nano as a credible use in food products. Bigger opportunities right now in detection and microbial contamination protocols. • increased use of nanotechnology in packaging, nutritional delivery systems (e.g. nutraceuticals) • Sensing technologies for food packaging Improved approaches to genetic modification toward more sustainable agriculture Public concern over the introduction of new technologies that affect food (and thereby health) • All the applications mentioned by FAO expert group including: ➢ Nanostructured (also termed nanotextured) food ingredients ➢ Nanodelivery systems for nutrients and supplements ➢ Organic nanosized additives for food, health food supplements, and animal feed applications ➢ "Inorganic nanosized additives for food, health food supplements, and feed applications" ➢ Food packaging applications ➢ Nanocoatings on food contact surfaces ➢ Surface functionalized nanomaterials ➢ Nanofiltration ➢ Nanosized agrochemicals ➢ Nanosensors for food labeling ➢ Water decontamination
What do you see as the major drivers of change in the agrifood nanotechnology sector?	• Need for productivity (high yield, low cost), food safety and water supply/purification/post-treatment • The nutraceuticals sector • Market chain and safety issues. • university researchers and USDA • Developing a clear regulatory pathway for product approval. • Trendiness of "nano". Not really dramatically better than current technology options • Government decision on acceptability of nano. • Technology development around nano encapsulation. • Clinical research on effects of nano particles.

	• Consumer demand and food shortages as the population continues to expand and climate change disrupts crop growth • Cost effective agriculture • Food and agricultural workers will increasingly be exposed to nanotechnology and thus, new management practices, and development and production distributed over multiple countries and carried out by people from multiple cultures. Such new work circumstances call for skills not traditionally taught in school: communications, working in teams, problem-solving, and so on.
What do you perceive as the current state of the agrifood nanotechnology workforce?	• little expertise (except in the sciences) • Mostly growing out of traditional disciplines: Microbiology, materials science • Inadequate or insufficient. • Adequate given prospects. • not a substantial workforce - most who work in nanotech (beyond research) are undertrained • Fine for execution of production. Need to build skills for R&D in this area. • small demand now but will grow • Vestigial, which is common to most industrial components outside of electronics where the nanoscale is an essential factor.
What are the consequences of the developments in nanotechnology on future skills needs in the agrifood sector?	• Opportunities for high productivity, enhanced nutrients in food and safer food and water • Need more technical workforces. • skill development not as important as imagined...on the job training through health and safety should be sufficient • Specific training on new developments. Can be done at both college and company levels. • need more technical skills to assess nanotechnology-enabled food products • To the extent that nanostructures become a principal building block of innovative new materials, this will affect agrifood machinery. As nano-enabled modifications to agrifood are employed, i.e. nano-enabled systems biology and cellular modifications, it will be necessary to provide a better basis for nanoscale environment, safety, health (benefit/risk) decisions • Employers are not too worried about the skill needs and even when they did, the theme of what we heard was actually much more generalized than technical. You know, what we heard over and over was that people need to be interdisciplinary. They need to have knowledge from a variety of different areas but the employers didn't naturally start talking about particular technical skills that they needed, the message was a bit more generalized skills.
What do you see as the major skill shortages in agrifood nanotechnology sector?	• Nano understanding • Individuals who can staff special tool needs, microscopists, etc. • Risk assessment for all forms of exposure to engineered nanoparticles. • R&D into nanotechnology. Equipment able to deliver nano products on a commercial scale. • physical and chemical characterization of nanomaterials in food and food packaging
What do you see as the major skill needs in agrifood nanotechnology sector?	• need both nanoscience and agrifood science skills • EHS researchers who can address gastro-intestinal implications. • R&D into nano technology. Equipment able to deliver nano products on a commercial scale. • technical capacity for measuring nanomaterials in foods and packaging

What skill needs and shortages should be anticipated?	• insufficient nano in ag research/educational programs in US • Environmental chemistry and toxicology for nanomaterials released intentionally or unintentionally into food production environments, from farm to factory. • health and safety, environmental impact • R&D into nano technology. Equipment able to deliver nano products on a commercial scale. • Nanoscale S&E will lead to very rapid advances in the understanding of the chemistry/physics of biological systems - what role will this play in agrifood? Sensing capabilities (size of sensor package, power levels, and ability to sense small quantities...) will improve dramatically - what role in agrifood?
How are skills needs being met?	• On the job training or other additional training • Mostly in doctoral programs but that needs to be moved into professional masters and technical colleges. • Training in ag & food chemistry is adequate. • excellent BS, MS, and PhD programs in the nano materials development - too little in the potential impacts and mitigation • Moderate trickle of R&D dollars being spent here. Hard to justify until legislation on nano is reached. • community colleges
What should be done to meet these skills needs?	• Increase the funding for programs that will educate personnel with both skills • Fund professional degree programs at levels lower than doctorate. • Basic science is missing. Training can follow. • Research dollars on the subject BEFORE implementation of massive nanotechnology approaches to agrifood. • Government should fund programs to advance the field. Provide grants and funding to advance topic. • Farmers need skills in personality development, openness to the interests of other private and public stakeholders, creativity, they need to be environment oriented (also in terms of what competitors are doing, and what regulations need to be anticipated); furthermore, they need human relations, entrepreneurship, and life-long learning skills. • Professional S&E societies associated with agrifood, working with their industrial counterparts should play a major role.
How could Agrifood Nanotechnology workforce development be improved?	• Expanding nano in ag/food research and training programs • Commitment from government, industry and education as a team. • Better appreciation of regulatory and consumer acceptance barriers to planned nanotechnologies. • Right now, I think workshops and short courses would be sufficient to help improve nano understanding, because food business will not invest until legislation approved. Will invest in (microbial/chemical) detection technology though. • CTE should be a main part of any nanotechnology driven educational reform. However, if CTE is to have a role in successfully preparing agrifood nanotechnology workforce, a look at program content, how to deliver CTE programs, and let go of what no longer works. The dichotomous silos of academics versus CTE must be eliminated and their supporting infrastructures must be re-imagined to meet the needs of the economy. As result of blurring of disciplines with the emergence of nanotechnology, so too must the lines that currently separate GE and academic education.

	• As the future cannot be accurately predicted, it is best that students acquire a broad background and many skills. Successful education in nanotechnology would require supplementation, not replacement, by a different instructional approach: just-in-time (JIT) education. • get the industries and trade unions working with universities and community colleges • The future of agrifood nanotechnology depends in large part on the development of an efficient and productive research and innovation infrastructure based on interdisciplinarity. It requires as an input collaborative research from several fields of sciences such as: biological sciences, physics, chemistry, electronic, engineering, mathematics, environmental and safety related disciplines, cognitive sciences, social sciences, etc. • Not only does the government have to invest in agrifood nanotechnology infrastructure, it must serve as catalyst for research using federal funding in the value network. Academic institutions can leverage this investment to commercialize technology, and facilitate new venture development. This requires business incubators, a viable venture capital network, and a globally competitive workforce with world-class education and skills.
Do you have any other suggestions for policy makers which could help to fulfill skill needs related to present and future development in nanotechnology and agrifood nanotechnology development more specifically?	• If nano is to be used in agricultural and food industries then a large investment (at every level...equipment, biology, chemistry, packaging etc. is needed now. Both Gov. and Industry must invest in R&D. • Development and propagation of nanoscience training at all degree levels: AA, BS, MA, PhD • Regulation needs to be negotiated with regulated and less uncertainty is more important than perfection. Develop regulations that sunset so improvements can be incorporated over time. • In my opinion, government needs to make decisions about nanotechnology law. Then they need to provide oversight of the industry, but get out of the way of technical advancement. Technology development should be done in 4 year Universities rather than vocational venues because the technology requires expansive skills development only acquired in 4 year school and graduate work. • implementation of STEM education plans across all levels of education • Facilitate R&D by providing more resources for academia and industry, and colleges. Also engage all of these stakeholders including public when framing agnano and nano food policies. • ongoing formative evaluation of new educational programs • There are major changes coming at all levels of the education system (K-gray). Education has traditionally been slow to change, yet rapid technology change (with nanotechnology as a poster child) compels more rapid introduction of new materials. Digital education aides may provide the means to accomplish this, but the introduction of that technology will require a concerted effort and will be expensive to implement. Policy is needed to keep that effort focused and effective. • States should coordinate the public schools, community colleges and four-year institutions with their workforce development strategies. This will achieve a coordinated and responsive delivery system for training a highly skilled nanotechnology workforce.
One key finding from the stakeholder survey	• We need universal nanoliteracy education

findings I sent to you is the lack of knowledge in nanotechnology of key stakeholder groups for example members of the AAAE and AHRD. What do you think the impact of these on nanoskill development?	• The impact may be significant. There is therefore the need for these organizations to organize workshops and conferences specifically on nanotechnology or create a track in their annual conferences on nanotechnology. I know for certain that the IFT does it • I think is a matter of time, and nanotechnology may be so universal that ordinary citizens will have the basic knowledge of it, as ICT is now as compared to when it was emerging.
Industry stakeholders are of the view that academia put the 'cart before the horse" and that all aspects of impact of nanotechnology has hugely been exaggerated. What are your thoughts?	• Certainly, there is a certain level of hype surrounding nanotechnology—both in terms of what is being promised, and the consequences that are feared. And yet, as an emerging technology, we cannot not easily dismiss. The term 'nanotechnology' may be a misnomer and even a passing fad, but our ability to manipulate matter at the smallest scales will continue to improve, leading to increasingly sophisticated materials and devices that are engineered at the nanoscale. This will continue to open up exciting new possibilities for technologies that can change and improve our lives and the world in which we live. • I do not think there has been any deliberate hype of nanotechnology. Yes! Some of the claims may sound fictional now, but if we look into the future the potential advances are limitless. Industry may have said the same thing if current advances in IT have been described to them 30 years ago. • Industry are driven by profits and therefore they look at advances from a very short term perspective and how things can be turned around. Academics get excited about prospects. • I think this is, because of the way researchers work. In academia they like to put things in nice neat little silos. The policy community and the education community began talking about nanotechnology as a very unique individualized skill set and started talking about jobs in terms of nanotechnology jobs and possible future gaps. I have come to realized from my research that the labor market does not view nano that extensively; they do not even think of nanotechnology jobs, because depending on how it is applied and where it is applied the skills or knowledge is different and I guess that the actual manipulation at the nanoscale is an engineering skill you need. The general skill requirement is like any other required by every 21st century worker.

Table A2. *Qualitative Expert Elicitation – Academic Experts*

Question	Key Responses
As your Institution train/assess/recognize skills of people from various sectors of the economy, what are the most important skills increasing the adaptability to	• A combination of technical, engineering knowledge with financial and decision making skills. • Basic science concepts, social dimensions of technological systems • communication, communication, communication skills • Need and salary attractiveness • Strong analytical skills, flexibility and adaptability, the ability to collaborate, and, most important, creativity and innovation. • The ability to think and problem solve

Question	Key Responses
change and occupational mobility of people?	• ability for self-directed learning • Willingness to learn a basic technical background • Workplace and corporate change is having a large impact on skill demands already and the impact of nanotechnology exacerbate these demands
In your own words, what do you think nanoscience education should be? Specify the education level that you are most interested in.	• All degree levels...our program focuses on MS and PhD but we work with community colleges, undergrads and industrial personnel • Enough science to select a specialization with some knowledge in HS and other important societal issue sets. • I think specialization is most important at the doctoral level. I think nano-science education should mostly be good science education. If individuals are well prepared in the fundamental of chemistry, I believe they will be well equipped to learn how nanomaterial concepts. • Nanoscience (at BA to PHD level) is not fundamentally different from any other education in agrifood science. Better training in governance and social dimensions of technical systems is needed across the board. • health and safety, environmental/health impacts, basic material and colloidal science • College level chemistry/physics/food/micro. • across the board improvement in STEM education and love of science and engineering "stuff" • bachelor/technical levels
What knowledge should students have prior to starting a nanoscience program in college?	• Science and Math background/degree • Math and STS. • 2 years of chemistry • High school physics, chemistry, better understanding of social and policy dimensions of science and tech. • Nanoscience is not a new science. It is chemistry and colloidal science using new tools that can evaluate materials at a smaller scale. Too much emphasis training students in "nanoscience" is a waste of time and money. The fundamentals are not new - just the tools. • Chemistry/physics/food/micro. • STEM subject matter expertise • basic STEM and literacy skills
In high school, what concepts should students understand before going into a college nanoscience program?	• strength in science and math • Incorporate nanoscale science and engineering into all levels of STEM education • Math and STS. • chemistry, physics, mathematics • nothing different -stick to basic sciences • Chemistry/physics/food/micro. • STEM subject matter expertise • the interdisciplinarity of STEM and ethics
Do you think nanoscience is better taught as interdisciplinary, integrated courses or through traditional, discipline-specific	• I prefer discipline specific courses for undergrads and nanoscience degree program for grads • Traditional discipline specific with some integrated courses. • I think the disciplinary approach will continue to work well at the undergraduate level. At the doctoral level I see great potential for interdisciplinary efforts (chemists, engineers, life scientists, etc.).

Question	Key Responses
courses (i.e., biology, chemistry, physics, and/or math)? If both, which would you emphasize?	• Start with traditional and advance to interdisciplinary. • some of each • Nanotechnology by its nature demands not only a strong foundation or "core," in content knowledge of physics, chemistry and biology but also the ability to apply it to the real world, and both are essential to develop broader competencies like critical thinking and problem solving.
What foundational concepts from nanoscience do you think are most crucial to teach? For example, scale and energy are often cited. What others can you suggest?	• Those are important but limited...size generally but surface area to volume ratio and nanochem and nanobio principles may be the most important for Ag/Food • EHS. • Quantum physics/biochemistry/material sciences • length and time scale, modeling and simulations • modeling • Embed nanoscale science and engineering education in internationally benchmarked standards and curriculum at all levels of education, but especially in the K–12 developmental progression
What do you think is the role of laboratory experiences and demonstrations in nanoscience education? Can you give a few examples and specify how they contribute to student understanding?	• They are critical. Our curriculum has lab as well as lecture courses, but I subscribe to a phrase used in another university "Research is how we teach" • Uncertain how important they are. For younger students they are much more important. • Organic chemistry is important to understanding a major class of nanomaterials. Transition metal chemistry is similarly applicable to other materials. • Just tools to "visualize" and analyze nano-samples is needed...XPS, SEM, XRS, etc. • Very important. • labs are critical to teach foundational skills and long term love of science • understanding errors
What tools, in general (including modeling tools) do you know of or can you recommend that can be adapted for labs or demonstrations?	• Modeling and visualization is critical, but nanochem & nanobio labs looks like conventional labs except they need better hoods and particle counters. In order to capture imaginations we use highly visual experiments...e.g. dye dilution for kids, SEM pictures for high school, college and beyond...If I picked a single tool it would be an SEM • Modeling is a great example. Quantum effects is up there as well. • NSF has funded a whole series of nanotechnology in undergraduate education programs. However, I don't believe there is a common resource for materials developed by these efforts. One would have to do an award search at NSF and query individual investigators. It would be painstaking. • The "Toolbox" approach to interdisciplinary research • New demos aren't needed. Stick to the standards that are a larger scale - they are easier for younger students (and newer students to the field) to adsorb
What nanoscience education materials are you aware of that you think are particularly good?	• There are many books and many educational levels are addressed...it would be hard to name just one or two. • None though I find some interesting research ethics materials at the HHS site. • We developed our own but based on concepts from the Ramaswami Small and Milford text.
In a nanoscience program, what do you see as the	• We initially focus on breadth (in the classroom courses) depth (in the laboratory and OJT is an internship is possible

Question	Key Responses
balance between academic learning, laboratory training, and on-the-job training?	• 1:1:1... Unfortunately we are seeing 1:2:3. I believe academia still hasn't found its footing. • I see nano-science as a specialization at the doctoral level. At that point the 3 areas merge together so roughly a third, a third, a third. • 1/3, 1/3, 1/3 • Heavy on academic learning until students understand the basics. Then heavy on lab and on-the-job learning. • 50%; 30%, 20%

Table A3. *Qualitative Expert Elicitation – Industry Experts*

Question	Key Responses
What issues have the most significant impact on your activities and on employment as a result of advances in nanotechnology and what has been the impact?	• EHS research. • Advancements are continuing, but little can be done until government makes a decision on how nano can be used commercially. • Uncertainty in the regulatory framework • No coherent regulatory policy • The fear of public backlash and public acceptance
What do you see are the main human resource challenges for employers in the agrifood nanotechnology sector? Is lack of adequate training a large challenge? How have the challenges changed over the past 5 years?	• Marketing product lines involving nanoscience • The need is on the University side versus on the company side. There is still great learning to be done on how to apply the different techniques being studied. Once we understand how to make effective nanoparticles, the commercialization will be entrepreneur led. • Current institutional arrangements, including the lack of incentives for the private sector to innovate for sustainability, and the lags inherent in the path dependent nature of innovation, contribute to lock-in, as does our incapacity to easily grasp the interactions implicit in complex problems, referred to here as the ingenuity gap. Nothing has really changed in the past five years with our education system to address this ingenuity gap • When it comes to technical skills things have change because that naturally comes with the advances with the technology. What has not really change is how best train students to acquire the necessary social skills.
Do you expect the number of people trained in the nanoskills the agrifood sector needs to be sufficient, or do you see a gap and is it growing? What occupations are most difficult to fill with qualified workers? What skills are most lacking for the core occupations in agrifood sector?	• It is growing. We need more young people with math and science skills to tap as a resource. • Nanotechnology is transdisciplinary so we do not need specific agrifood nanotechnology training, but students to have the required nanoskills that can be tapped to work in the agrifood sector. By the way I like the term agrifood. • The buildup in the expectation of the number of workers that would need nanotechnology skills was much exaggerated both in the numbers and the type of skills. • The education sector has responded to the societal promotion of environmental issues with young people enrolling in environmental science programs. Environmental science is generally focused on preserving functioning biological systems; it is not about producing saleable products in a sustainable manner. In contrast, agrifood requires the management of biological, economic and human resources to produce a profit; agriculture can only be sustainable as

Question	Key Responses
	long as it is profitable. Rather than assuming environmental science graduates can be used to fill the gap, perhaps a better approach would be to boost the 'public good' credentials of agricultural and food science degrees. Perhaps nanotechnology will make agrifood sexy but as a company we doubt there will be enough well trained job applicants. Nevertheless we compensate that with OJT.
Over time, skills required for particular occupations are likely to change either because of the occupation itself has changed or because new needs create new tasks, calling for new jobs. What have been the major changes/shifts in demand for skills in the agrifood sector in the last few years? How have you managed these changes (staff training, recruitment of new people, etc.)?	• I assess others. There has been increased recruitment in the industry. • Because of ICT, nanotechnology, globalization, and other competitive forces, have all combine to alter how work gets done. We are now a more “flatter” organization with less hierarchy and lighter supervision where workers experience greater autonomy and personal responsibility for the work they do than just a decade ago. Work also has become much more collaborative, with self-managing work teams increasingly responsible for tackling major projects.

Table A4. *Stakeholder suggestions for policy makers to fulfill skill needs*

Stakeholder	Key Responses
Industry	• Government should not see STEM education, Immigration Policies, Outsourcing/Offshoring and other policies as standalone policies, but issues that are intertwined • Policy makers should not fund academic research just for funding sake • They should not just being putting in research funds to the Universities. Government should tailor research dollars to what will create real value for the citizens and not just to satisfy the ego of scientists • Proper inventory needs to be taken on the needs of industry to tailor academic research. Again industry-Academia relationship should not only be a mere rhetoric but something that is done with committed intentionality • Academics are making too much noise about nanotechnology to attract research funding without any input from industry or without proper societal needs assessment • Industry and academia are pretending to collaborating, but actually they are on different wavelengths. So far as they are on different wavelengths, there will be substantial skill gaps in the future
Government	• Improve communication of both risks and benefits of technology to all stakeholders. • A broad skills inventory for agrifood would be a valuable initiative. Significant investment in community outreach and education would be desirable with the recognition that society is the ultimate stakeholder. Commercial/industrial partnering would be a valuable first step before each individual agrifood sector solicits government independently. • Retrain existing workers not increase visas
Education	• Exposure to nanoscience and technology should begin as early as possible. When we wait for students to take science classes in high school we have missed the years when they are most open and curious and ready to learn. Our program seeks to expose younger students to the options and teach them the basics and the vocabulary needed to follow the academic track required. But, most importantly, we make it fun for them so

Stakeholder	Key Responses
	they expand their interest and pursue their education with enthusiasm. Many students in the underserved communities are already lost be the time they arrive at high school level. They are intimidated by science or uninterested because they do not see the need for it. They have not been led to understand the application in their own lives. I understand that my response is somewhat peripheral to the survey you are conducting, but at its core, it is most essential if we are to have trained individuals to hold the nano jobs of the future. It's part of the larger picture.
AAAE	• This study is an interesting idea, but having an Ag education background and working in the field of biosafety (which was new to me), I do not think that Ag education faculty members have the background knowledge of nanotechnology in which to provide effective information for this project. • Co-host conferences which feature the theoretical, practical, and applicable by corresponding researchers, teachers, business, and consumers • I believe that as the industry expands and real jobs develop in this sector (which you would only know through a pretty detailed Workforce Gap Analysis), that a governmental investment must be made in all sectors, including secondary/postsecondary CTE, continuing professional development (online for professionals in other sectors), 2+2 Applied BS and traditional BS programs, and graduate-level (for credit) certifications. I have had a bit of experience as a dean who worked in the emerging Wind Energy sector in TX with a $2.5M investment from TX Workforce Commission. • Insure a supply of a multiple level of employee in the industry. Not just 4 year, degree seeking individuals. But CTE 2 year as well
AHRD	• More training and development initiatives within Higher Education and Workforce Development Initiatives • while developing the employee population implement a help desk function for technical information and help - i.e. live chat • Provide more direct financial aid to students in the form of grants if studying in certain fields. • improve the general skill level of students • keep the government out of it; they will just screw it up • It is extremely difficult to focus the attention on agrifood nanotechnology. Industry does not tend to be organized that way. For example, they will still need accountants, supervisors, quality specialists, operators, as well as specialized personnel. A big issue will be convincing students to consider this career field. Second, will be the issue of whether the number of people needed in specialized occupations will be sufficient to warrant program development in secondary, vocational, and higher education. • Reform current agriculture policies so that unsustainable practices are gradually made unprofitable. Agribusiness giants like Cargill and ADM have the funds to conduct large-scale nanotechnology research, they just lack incentive to do so. • Nanotechnology is invasive and the need for wisdom is far greater than the need to perform higher level math. Develop self-auditing policy to assure the future safety of agribusiness by protecting consumers. • Use a systems perspective to encourage the creation of zones or regions like Silicon Valley--create conditions for community colleges and higher ed institutions to provide training and R&D
NAWDP	• First focus the educating people who are already involved in the industries where development will occur. Build a cooperation and partner with Community Colleges to build these curricula and train the workforce on site. • Agriculture needs to attract people beyond faculty crop scientists to evolve and will need to create vibrant career tracks beyond educational institutions and Ag Stations. These people will need to be offered competitive wages before they will consider entry.

Stakeholder	Key Responses
IFT	• Develop a comprehensive federal plan to be adapted to suit various states that establishes goals by workforce, economic development, public education, business and others that includes ongoing collaboration and recommendations toward building and maintaining a nanoskilled workforce and that is reviewed annually and serves as a guide for planning and setting policy by relevant agencies • Chemistry is core science that must be built upon. • Existing federal regulations of food and food-related nanomaterials are not completely adequate • Many food science and technology graduates do not possess the skills and attributes businesses consider important. The disparity between skills identified by businesses as important, and skills identified as usually being possessed by FST graduates suggests that many graduates do not possess the technical skills that are considered important by business. Educational policy makers will have to devise policies that will synchronize the needs of industry with what is thought at the colleges and universities • Tertiary and higher education providers should engage more directly with food processing businesses about curricula and outcomes to ensure that the skills developed through further education better match those required by industry.

Appendix B – Elicitation and Survey Questionnaires

Quantitative Expert Elicitation Questionnaire

PART 1 – BACKGROUND AND EXPERTISE

1 What is the level of your involvement (e.g. expertise, following developments in field, using or making products, overseeing products, teaching, policy studies or making, etc.) in Agrifood Nanotechnology?

Very Involved	Involved	Somewhat Involved	Not very involved	Not at all involved

2 Please indicate which sector you belong to (Check as many as apply):

a) Academia/Education
b) Government
c) Industry/Business
d) Third Sector/NGO
e) Public/Consumer/User

3 What is your highest academic qualification?

a) Two year Associate degree
b) BS/BA
c) MS/MA/MPhil
d) Professional degree e.g. J.D, MD etc.,
e) PhD
f) Other

PART II – STAKEHOLDER ANALYSIS

4 Who are the key stakeholders in the agrifood nanotechnology sector? Please use the following typology to prioritize them on a scale of 1 (lowest) to 5 (highest): (1) Power—is the stakeholders' power to influence skill development in agrifood nanotechnology significant or relatively limited? (2) Proximity/Legitimacy—is the stakeholder directly impacted by the consequences of action or inaction on the issue at stake i.e. skill needs for agrifood nanotechnology? (3) Urgency—what is their stake? Is the stakeholder prepared to go to any lengths to address the issue at stake with or without other stakeholders?

Stakeholder	Power	Proximity/ Legitimacy	Urgency
Academia			
Institutions with infrastructure and programs for K12 nanotechnology Education;			
Institutions offering TVET/CTE certificate Programs;			
Institutions offering Bachelor Degree Programs;			
Institutions offering Master Degree Programs;			
Institutions offering Doctoral Degree Programs;			
Institutions with Nanotechnology Workforce Development Programs and Infrastructure;			
Professional and Academic Bodies of interest e.g. AAAE; IEEE; AHRD etc.			
Other (please specify)			

Government			
Government (National) Laboratories and Centers			
Government Agencies e.g. FDA, USDA, USDL etc.			
Office of the President/Governors			
Legislature – Federal/State			
Judiciary –Local/State/Federal			
School Boards			
Other (please specify)			
Industry/Business			
Large Scale Agrifood Companies			
Medium Scale Agrifood Companies			
Small Scale Agrifood Companies			
Trade Associations e.g. Chamber of Commerce			
Farmers and Farmer groups and Associations			
Labor Unions			
Other (please specify)			
Public			
Consumers			
Users of agrifood nanoproducts			
Other (please specify)			
Third Sector			
Advocacy Groups			
Civil Society Organizations			
Other (please specify)			

PART 2 - AGRIFOOD NANOTECHNOLOGY EMPLOYABILITY SKILLS AND COMPETENCIES

5 Please rank the following agrifood employability skills and competencies that will be needed most in the era of nanotechnology. On a scale of 1 – 5, please rank each of the following skills with 5 being most needed and 1 being the least needed

Commercial, management and societal knowledge competencies	Rank
Technology marketing	
Technology strategy	
Finance (Start-up Venture and Corporate)	
Project Management	
Research and Development Management	
New Product Innovation	
Entrepreneurship	
Risk Assessment and Management	
Public Communication	
Technology policy	
Intellectual property	
Ethics	
Environmental and Sustainability	
Legal	
Other (please specify):	
Leadership	
Other (please specify):	
Other (please specify):	
Soft Skills	
Team working	
Verbal Communication	

People friendliness	
Lateral thinking	
Other (please specify):	
Other (please specify):	
Other (please specify):	
Technical Skills	
Manufacturing skills	
Chemistry, physics, materials	
Hardware	
Engineering	
Miscellaneous skills, training	
Imagery, optics, microscopy	
Computer skills	
Lab equipment, instruments, analysis	
Farm Business Management	
Problem-solving, critical think	
Nano info, products, industry	
Electronics, mechanical, vocational	
Design, drafting, creative	
Basic employment issues	
Innate, natural talents	
Math	
People skills	
Other	
Research, lab, hands-on experience	
Business skills	
Language skill development	
Basic literacy	

6 Which technical knowledge competencies would you like delivered from nanoscience and nanotechnology education for placement in Agrifood nanotechnology Sector? **Check as many as appropriate.**

Technical knowledge competencies	Check
Nanoscale physical phenomena (quantum effects)	
Chemistry:	
Colloidal Chemistry	
Wet Chemistry	
Inorganic Chemistry	
Organic Chemistry	
Molecular Chemistry	
Nano - biology interfaces	
Metallurgy	
Material Science	
Fabrication techniques (Top-down and bottom-up):	
Lithography (E-beam, Optical, Photo, Micro, Stereo, Soft)	
Embossing (Hot, Cold)	
Printing	
Etching (Dry, Wet, Reactive ion, photochemical)	
Plasma Enhanced Chemical Vapor Deposition	
Molecular Beam Epitaxy	
Thermal Evaporation	
E-Beam Evaporation	

Milling (Focused Ion beam)	
Sol Gel	
Microinjection Molding	
Laser Micro Machining	
CNC micromachining	
Bonding and Joining	
Self-Assembled Monolayer	
Layer by Layer	
Chemical Mechanical Polishing	
Characterization and analysis techniques:	
Scanning Electron Microscopy	
Transmission Electron Microscopy	
Scanning Tunneling Microscopy	
Atomic Force Microscopy	
Optical Microscopy	
Fluorescence Microscopy	
Confocal Microscopy	
XDS	
XPS	
SIMS	
X-ray	
Design methodologies and product development	
New materials, properties and their selection	
Near nanoscale devices and structures	
Nanoelectronics	
Photovoltaics and Photonic	
Technical communication (Written and spoken)	
Computational models and software (Modelling, CAD, CAM)	
Health and Safety	
Other (please specify):	

PART IV - IMPACT ON SKILLS

7. Skills gaps arise when the current employees do not fully meet the skills requirements for their job functions. In your opinion to what extent do job-requirements stemming from developments in nanotechnology currently lead to skill gaps in agrifood industry?
   a) No skill gaps
   b) Limited skill gaps
   c) Substantial skill gaps
   d) Do not know

8. To what extent do you expect developments in nanotechnology to lead to skill gaps in the agrifood sector in the future?
   a) No future recruitment problems
   b) Limited future recruitment problems
   c) Substantial future recruitment problems
   d) Do not know

9. In your opinion what is the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in Nanotechnology?
   a) Increase wages
   b) (Further) automation and mechanization to substitute labor
   c) Try to postpone retirement older employees
   d) Recruiting workers from other sectors, or other countries

e) Recruiting young people from the education system
f) Use of specialized agencies/temporary workers/ headhunters
g) Restructuring the (work) organization
h) Increase internal job mobility in the company
i) Outsourcing and off shoring
j) On the job training
k) Participation of employees in off the job training and education programs
l) Stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes)
m) Other, namely........ ?
n) Do not know

10. What measure (s) should agrifood businesses take now to address skill needs?
a) Conducting a Skills Inventory
b) Applying/seeking funding to address needs
c) Using outside private consultants/providers to assist
d) Increasing retention efforts
e) Developed in-house skills training/mentoring
f) None
g) Working with the local educational institutions to provide training and recruiting
h) Predicting future skills needs
i) Other (please specify)

11. Do you think the higher education system (Universities, polytechnics, higher vocational education) in the United States is able to fulfill skill needs related to present and future developments in nanotechnology?
a) To a great extent
b) Somewhat
c) Very little
d) Not at all
e) Do not know

12. What should be improved within the higher education system to better fulfill skill needs related to developments in nanotechnology? (Please select as many as apply).
a) Stronger cooperation with companies
b) Increase the supply of graduates in relevant fields
c) Start new types of higher level science courses
d) Improve the theoretical level of education programs on Bachelor/Masters level More possibilities for (part-time) PhD programs
e) More specialization (i.e. in-depth knowledge of specific domains) within science
f) Less specialization within science, but more general knowledge of scientific domains within science
g) More attention for personal skills in education
h) More attention for technical developments in non-technical studies
i) More opportunities for training courses of experienced professionals to update skills and acquire new skills
j) Improve international cooperation
k) Other, namely... ?
l) Do not know

13. Do you think the vocational education and training (VET)/Career and Technical Education (CTE) system in the United States is able to fulfill skill needs related to present and future developments in Nanotechnology?
    a) To a great extent
    b) Somewhat
    c) Very little
    d) Not at all
    e) Do not know

14. If relevant, what should be improved within the vocational education and training/Career and Technical Education system to better fulfill skill needs related to developments in Nanotechnology? (Please select as many as apply)
    a) Stronger cooperation with companies
    b) Increase the supply of graduates, especially in relevant fields
    c) Start new types of vocational specializations in the education system
    d) Improve the theoretical level
    e) More attention for personal skills in vocational education
    f) More attention for technical developments in non-technical studies
    g) More opportunities for training courses of experienced professionals to update skills and acquire new skills.
    h) Improve conditions for companies to employ apprentices and interns from the vocational education system
    i) Improve international cooperation
    j) Other, namely..
    k) Do not know

15. What is your opinion regarding the government's role in development of nanotechnology? Select one option.
    a) 1 = Industry leads developments, Government involvement is not necessary
    b) 2 = Industry takes the initiative and Govt. oversees the nanotech industry
    c) 3 = Govt. should co-invest in industry-led nanotechnology developments
    d) 4 = Govt. should co-invest heavily & offer strong incentives to industry

16. Do you have any other suggestions for policy makers which could help to fulfill skill needs related to present and future development in nanotechnology and agrifood nanotechnology development more specifically?

17. Thank you for participating in this important project. Please indicate if you like the findings from this survey to be made available to you. In case you would like to receive a copy, please leave your e-mail address: (still warranting anonymity; it will never be possible to trace back individual answers).

Qualitative Elicitation – Semi-structured Interviews

1 What do you see as trends in the agrifood nanotechnology sector?

Drivers of Change

2 What do you see as the major drivers of change in the agrifood nanotechnology sector?

Current State of Workforce

3 What do you perceive as the current state of the agrifood nanotechnology workforce?

Skill Shortages

4 What are the consequences of the developments in nanotechnology on future skills needs in the agrifood sector?

5 What do you see as the major skill shortages in agrifood nanotechnology sector?
6 What do you see as the major skill needs in agrifood nanotechnology sector?
7 What skill needs and shortages should be anticipated?

Measures to Meet Demand

8 How are needs being met?
9 What should be done to meet these needs?

Recommendations

10 How could workforce development be improved?

Specific Elicitation Questionnaire for Industry Experts

1. What issues have the most significant impact on your activities and on employment as a result of advances in nanotechnology and what has been the impact?
2. What has been the employment trend in your company (now versus 5 years ago)? Percentage male versus female, core types of jobs, training requirements for these jobs, special qualifications needed, training providers (i.e., you or some other org), in-country or out of country (which countries), percentage of your workforce that has had experience doing similar work in other sectors before starting to work in nanotechnology (what types of work and in what sectors)
3. What do you see are the main human resource challenges for employers in the agrifood nanotechnology sector? Is lack of adequate training a large challenge? How have the challenges changed over the past 5 years?
4. Do you expect the number of people trained in the nanoskills the agrifood sector needs to be sufficient, or do you see a gap and is it growing? What occupations are most difficult to fill with qualified workers? What skills are most lacking for the core occupations in agrifood sector?
5. Over time, skills required for particular occupations are likely to change either because of the occupation itself has changed or because new needs create new tasks, calling for new jobs. What have been the major changes/shifts in demand for skills in the agrifood sector in the last few years? How have you managed these changes (staff training, recruitment of new people, etc.)?

Specific Elicitation Questionnaire for Academic Experts

1 As your Institution train/assess/recognize skills of people from various sectors of the economy, what are the most important skills increasing the adaptability to change and occupational mobility of people?

When to teach nanoscience:

2 In your own words, what do you think nanoscience education should be? Specify the education level that you are most interested in.
3 What knowledge should students have prior to starting a nanoscience program in college?
4 In high school, what concepts should students understand before going into a college nanoscience program?

How to teach nanoscience:

5 Do you think nanoscience is better taught as interdisciplinary, integrated courses or through traditional, discipline-specific courses (i.e., biology, chemistry, physics, and/or math)? If both, which would you emphasize?
6 What foundational concepts from nanoscience do you think are most crucial to teach? For example, scale and energy are often cited. What others can you suggest?
7 What are a few of your favorite examples that illustrate the concepts mentioned in question 3?

Tools to use in teaching nanoscience:

6. What do you think is the role of laboratory experiences and demonstrations in nanoscience education? Can you give a few examples and specify how they contribute to student understanding?
7. What tools, in general (including modeling tools) do you know of or can you recommend that can be adapted for labs or demonstrations?
8. What nanoscience education materials are you aware of that you think are particularly good?
9. In a nanoscience program, what do you see as the balance between academic learning, laboratory training, and on-the-job training?

Survey Questionnaire for Industry [Business] Stakeholders

PART 1 – SIZE AND BUSINESS SECTOR

1 Which of the following best describes your current status?
- a) We are a start-up Nanotechnology company without products on the market
- b) We have Nano product(s) on the market
- c) We are a Nano research company
- d) We manufacture Nano products but none are related to Food and Agriculture

2 Do you plan to develop Agrifood Nano research capabilities, products or production facilities in the future?
- a) Yes
- b) No

3 How many people are employed at your Company?
- a) 50 employees or less
- b) Between 51 and 200 employees
- c) Over 200 employees

4 Do you produce an end or finished Agrifood Nano product to be used by consumers or Industry?
- a) Yes
- b) No

5 What is the level of your Organization's Application of Nanotechnology Knowledge in Materials, Processes, Devices and Services?
- a) High (over 75% products and processes)
- b) Medium (between 75%-40% of products and process)
- c) Low (less than 40% of products and processes)
- d) Not aware

PART 2 - HUMAN RESOURCES RECRUITMENT AND EMPLOYEE CHARACTERISTICS

6 What is the preference for qualifications in your organization?
Check as many as appropriate.
- a) TVET/CTE Certificate
- b) Two-year degree
- c) Bachelors' degree (science or engineering)
- d) Master's degree (single discipline in science or engineering)
- e) Interdisciplinary Master's degree (Combination of science, agriculture, engineering and management knowledge)
- f) Master's degree (Business, Management, Economic or Law)
- g) PhD. (research in any applicable nanotechnology area)
- *h)* Other (please elaborate):

7 Do you employ people specifically for their nanotechnology know- how?
a) Yes
b) No
c) Not Applicable

8 Do you have human resources problems related to qualifications listed above with nanotechnology know-how?

Qualification	*Yes*	*No*	*Not Applicable*
TVET/CTE Certificate			
Two-year degree			
Bachelors' degree (science or engineering)			
Master's degree (single discipline in science or engineering)			
Interdisciplinary Master's degree (Combination of science, agriculture, engineering and management knowledge)			
Master's degree (Business, Management, Economic or Law)			
PhD. (research in any applicable nanotechnology area)			
Other:			

9 If answered positively to the above question, please identify the problems.
Check as many as appropriate

	TVET	2-year	BS/ BA	Masters	Inter. MS	MA/ MBA	PhD	Others
Availability of right skill set in graduates								
Broad Knowledge of topics and applications								
Expertise in specific processes and techniques								
Availability of trained technicians								
Continued professional development								
Cost of employees								
Other								

TECHNICIANS

10 As manufacturing continues to evolve, what are the top *technical* skills that technicians will need most? On a scale of 1 – 5, please rank each of the following skills with 5 being most needed and 1 being the least needed

Technical Skills	1	2	3	4	5
Manufacturing skills					
Chemistry, physics, materials					
Hardware					
Engineering					
Miscellaneous skills, training					
Imagery, optics, microscopy					
Computer skills					
Lab equipment, instruments, analysis					
Problem-solving, critical think					
Nano info, products, industry					

Electronics, mechanical, vocational					
Design, drafting, creative					
Basic employment issues					
Innate, natural talents					
Math					
People skills					
Other					
Research, lab, hands-on experience					
Business skills					
Language skill development					
Basic literacy					

11 As manufacturing continues to evolve, what are the top three *personal* skills that technicians will need most? On a scale of 1 – 5, please rank each of the following skills with 5 being most needed and 1 being the least needed

Personal Skills	1	2	3	4	5
Basic employment issues					
Language skill development					
Innate, natural talents					
Design, drafting, creative					
Problem-solving, critical thinking					
Social skills, personality					
Technical, multidisciplinary, miscellaneous					
People skills					
Manufacturing skills					
Business skills					

12 Are you currently able to hire technicians who are adequately trained for the job?

a) Yes
b) No
c) Sometimes

13 When hiring new technicians, what type of expertise must the candidate have? Please identify all that apply and rate their importance as very important, somewhat important, or not important.

	very important	somewhat important	not important
Nano materials handling safety			
Nanofabrication processes			
Thin Films in nanofabrication			
Advanced lithography and patterning			
Material modification in Nanofabrication			
Characterization and measurement of Nanofabrication structures			
Micro-electronic circuits			
Clean-room procedures			
Trouble-shooting and repair of nano equipment and processes			
Nanofabrication related statistics			
Packaging of nanostructures			
Laboratory equipment programming			
Experience with scanning and local probe tech			
Experience with wafer fabrication related equipment			
Bio-fabrication processes			

Opto-Electronics			
CAD CAM design			

14 It is important to identify the basic 21st century skill requirements necessary to successfully accomplish the specialized tasks/processes that you just identified. Other than the more common basic skill requirements including, reading, math skills, team work, communication, learning to learn, and problem solving, what other basic skills would be unique to these tasks? Please rate your choice in the order of preference?
Rate as many as appropriate using a scale from 1 (lowest) to 15 (highest)

21st century skill requirements	Ranking
Chemistry, physics, materials	
Computer skills	
Basic employment issues	
Understand nano, products	
Math	
Lab equipment, instrumentation, anal	
Miscellaneous skills, training	
Problem-solving, critical thinking	
People, sales, marketing skills	
Health & safety issues	
Electronics, mechanical, vocational	
Design, drafting, creative	
Innate, natural talents	
Manufacturing skills, product handling	
Read, comprehend scientific literature	
Language skill development	
Engineering	
Research, lab, hands-on experience	
Business skills	
Imagery/analysis, optics, micro	
Leadership Skills	

GRADUATES AND POST-GRADUATES

15 What are the different roles of graduates and post-graduates you employ?
Check as many as appropriate.

a) Science Research
b) New Product Development
c) Manufacturing and Production
d) Quality Assurance
e) Health and Safety
f) Documentation
g) Marketing
h) Venture Finance
i) Public Relation and Communication
j) Business development
k) Management
l) Other (please specify):

16 Which skill set and knowledge competencies do you value in graduate and post-graduate employees?

a) Specialist Single discipline (Physics, Chemistry, Biology, Mathematics, Engineering, Legal,
b) Food Science, Agriculture Education, Environmental or Management)

c) Generalist Multi-discipline (Physics, Chemistry, Biology, Mathematics, Engineering, Legal,
d) Agricultural education, Food Science, Environmental and Management)
e) Both
f) Not sure

17 To which commercial, management and societal knowledge competencies would you like graduates and postgraduates to have exposure? Please rate your choice in the order of preference?
Rate as many as appropriate using a scale from 1 (lowest) to 15 highest)

Commercial, management and societal knowledge competencies	Rank
Technology marketing	
Technology strategy	
Finance (Start-up Venture and Corporate)	
Project Management	
Research and Development Management	
New Product Innovation	
Entrepreneurship	
Risk Assessment and Management	
Public Communication	
Technology policy	
Intellectual property	
Ethics	
Environmental and Sustainability	
Legal	
Other (please specify):	
Other (please specify):	
Other (please specify):	

18 Which soft skills do you value most?
Rate as many as appropriate using a scale from 1 (Lowest) to 5 (Highest)

Soft Skills	1	2	3	4	5
Team working					
Verbal Communication					
People friendliness					
Lateral thinking					
Other (please specify):					
Other (please specify):					
Other (please specify):					

19 Which technical knowledge competencies would you like delivered from nanoscience and nanotechnology, graduates and post-graduates for placement in Agrifood nanotechnology Sector?
Check as many as appropriate.

Technical knowledge competencies	Check
Nanoscale physical phenomena (quantum effects)	
Chemistry:	
Colloidal Chemistry	
Wet Chemistry	
Inorganic Chemistry	

Organic Chemistry	
Molecular Chemistry	
Nano - biology interfaces	
Metallurgy	
Material Science	
Fabrication techniques (Top-down and bottom-up):	
Lithography (E-beam, Optical, Photo, Micro, Stereo, Soft)	
Embossing (Hot, Cold)	
Printing	
Etching (Dry, Wet, Reactive ion, photochemical)	
Plasma Enhanced Chemical Vapor Deposition	
Molecular Beam Epitaxy	
Thermal Evaporation	
E-Beam Evaporation	
Milling (Focused Ion beam)	
Sol Gel	
Microinjection Molding	
Laser Micro Machining	
CNC micromachining	
Bonding and Joining	
Self-Assembled Monolayer	
Layer by Layer	
Chemical Mechanical Polishing	
Characterization and analysis techniques:	
Scanning Electron Microscopy	
Transmission Electron Microscopy	
Scanning Tunneling Microscopy	
Atomic Force Microscopy	
Optical Microscopy	
Fluorescence Microscopy	
Confocal Microscopy	
XDS	
XPS	
SIMS	
X-ray	
Design methodologies and product development	
New materials, properties and their selection	
Near nanoscale devices and structures:	
Nanoelectronics	
Photovoltaics and Photonic	
Technical communication (Written and spoken)	
Computational models and software (Modelling, CAD, CAM)	
Health and Safety	
Other (please specify):	

PART 3 - IMPACT ON SKILLS

20 Skills gaps arise when the current employees do not fully meet the skills requirements for their job functions. To what extent do job-requirements stemming from developments in nanotechnology currently lead to skill gaps in your company?

e) No skill gaps
f) Limited skill gaps
g) Substantial skill gaps
h) Do not know

21 To what extent do you expect developments in nanotechnology to lead to skill gaps in your company in the future?

e) No future recruitment problems
f) Limited future recruitment problems
g) Substantial future recruitment problems
h) Do not know

22 What is the strategy of your company to address potential skill shortages and skill gaps that result from developments in Nanotechnology? Select all that apply

o) Increase wages
p) (Further) automation and mechanization to substitute labor
q) Try to postpone retirement older employees
r) Recruiting workers from other sectors, or other countries
s) Recruiting young people from the education system
t) Use of specialized agencies/temporary workers/ headhunters
u) Restructuring the (work) organization
v) Increase internal job mobility in the company
w) Outsourcing and off shoring
x) On the job training
y) Participation of employees in off the job training and education programs
z) Stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes)
aa) Other, namely........ ?
bb) Do not know

23 What measure (s) is your business taking now to address skill needs?

j) Conducting a Skills Inventory
k) Applying/seeking funding to address needs
l) Using outside private consultants/providers to assist
m) Increasing retention efforts
n) Developed in-house skills training/mentoring
o) None
p) Working with the local educational institutions to provide training and recruiting
q) Predicting future skills needs
r) Other (please specify)

24 Do you think the higher education system (Universities, polytechnics, higher vocational education) in the United States is able to fulfill skill needs related to present and future developments in nanotechnology?

f) To a great extent
g) Somewhat
h) Very little
i) Not at all
j) Do not know

25 What should be improved within the higher education system to better fulfill skill needs related to developments in nanotechnology? (Please select as many as apply).

m) Stronger cooperation with companies
n) Increase the supply of graduates in relevant fields

o) Start new types of higher level science courses
p) Improve the theoretical level of education programs on Bachelor/Masters level More possibilities for (part-time) PhD programs
q) More specialization (i.e. in-depth knowledge of specific domains) within science
r) Less specialization within science, but more general knowledge of scientific domains within science
s) More attention for personal skills in education
t) More attention for technical developments in non-technical studies
u) More opportunities for training courses of experienced professionals to update skills and acquire new skills
v) Improve international cooperation
w) Other, namely.. ?
x) Do not know

26 Do you think the vocational education and training (VET)/Career and Technical Education (CTE) system in the United States is able to fulfill skill needs related to present and future developments in Nanotechnology?

f) To a great extent
g) Somewhat
h) Very little
i) Not at all
j) Do not know

27 If relevant, what should be improved within the vocational education and training)/Career and Technical Education system to better fulfill skill needs related to developments in Nanotechnology? (Please select as many as apply)

l) Stronger cooperation with companies
m) Increase the supply of graduates, especially in relevant fields
n) Start new types of vocational specializations in the education system
o) Improve the theoretical level
p) More attention for personal skills in vocational education
q) More attention for technical developments in non-technical studies
r) More opportunities for training courses of experienced professionals to update skills and acquire new skills.
s) Improve conditions for companies to employ apprentices and interns from the vocational education system
t) Improve international cooperation
u) Other, namely...
v) Do not know

28 What is your opinion regarding the government's role in development of nanotechnology? Select one option.
e) 1 = Industry leads developments, Government involvement is not necessary
f) 2 = Industry takes the initiative and Govt. oversees the nanotech industry
g) 3 = Govt. should co-invest in industry-led nanotechnology developments
h) 4 = Govt. should co-invest heavily & offer strong incentives to industry

29 Do you have any other suggestions for policy makers which could help to fulfill skill needs related to present and future development in nanotechnology and agrifood nanotechnology development more specifically?

30 Please add any additional comments you may have concerning identified skill gaps or possible future skill needs in your workforce or recruiting challenges your organization has encountered.

31 Thank you for participating in this important project. Please indicate if you like the findings from this survey to be made available to you. In case you would like to receive a copy, please leave your e-mail address: (still warranting anonymity; it will never be possible to trace back individual answers).

Survey Questionnaire for Third Sector, Public, Government and Academia

PART 1 – BACKGROUND INFORMATION

1 Please indicate which sector you belong to (Check as many as apply):

a) Educational Institution
b) Government
c) Third Sector/NGO
d) Public/Consumer/User

2 What is the level of the involvement of your Organization/Institution/Department (e.g. expertise, following developments in field, using or making products, overseeing products, teaching, policy studies or making, etc.) in Nanotechnology?

Very Involved	Involved	Somewhat Involved	Not very involved	Not at all involved

3 Which of the following best describes the academic programs your institution is offering in Nanotechnology? Select all that apply (Please skip to question 9 if not an Educational Institution)

a) K-12 Education Programs
b) TVET/CTE Programs
c) 2 year Associate Degree Programs
d) Bachelor's Degree Program
e) Master's Degree Programs
f) Doctoral Degree Programs
g) Workforce Development Programs

PART II - FUTURE CURRICULUM DEVELOPMENT

4 Do you expect the role of nanotechnology in the education programs of your faculty/ department to increase or decrease in the next five academic years?

a) Strong increase
b) Increase
c) Remain the same
d) Decrease
e) Strong decrease
f) Do not know

5 In your faculty/department, how important are contacts with companies for the development of education/training curricula?

a) Very important
b) Important
c) Not very important

d) Not important at all
e) Do not know

6 With which company departments does your faculty/department discuss the skills your students should obtain?? *(Multiple answers possible)*
a) General management
b) Human resources
c) Research and development
d) Engineering and design
e) Production/operations
f) Do not know

7 What is the purpose of these contacts? *(Multiple answers possible)*
a) Exchange of information on a regular base
b) Exchange of information on an irregular base
c) Evaluation of adequacy of graduate skills
d) Cooperation in development of new courses or adapting existing courses
e) Traineeships/Internships
f) Research collaborations / joint research projects
g) We remain in contact with alumni
h) We train employees (lifelong learning/in-company training activities)
i) Do not know

8 Will your faculty/department start new education and training programs that include nanotechnology education in the next five academic years?
a) Yes
b) No
c) Do not know

9 What has been the role of companies in the development of these programs?
a) They have had an active role in developing the content of this program
b) They have had a passive role in developing the content of this program
c) They were not involved in the development of this program

PART III - AGRIFOOD NANOTECHNOLOGY EMPLOYABILITY SKILLS AND COMPETENCIES

10 Please rank the following agrifood employability skills and competencies that will be needed most in the era of nanotechnology. On a scale of 1 – 5, please rank each of the following skills with 5 being most needed and 1 being the least needed

Commercial, management and societal knowledge competencies	Rank
Technology marketing	
Technology strategy	
Finance (Start-up Venture and Corporate)	
Project Management	
Research and Development Management	
New Product Innovation	
Entrepreneurship	
Risk Assessment and Management	
Public Communication	
Technology policy	
Intellectual property	

Ethics	
Environmental and Sustainability	
Legal	
Other (please specify):	
Leadership	
Other (please specify):	
Other (please specify):	
Soft Skills	
Team working	
Verbal Communication	
People friendliness	
Lateral thinking	
Other (please specify):	
Other (please specify):	
Other (please specify):	
Technical Skills	
Manufacturing skills	
Chemistry, physics, materials	
Hardware	
Engineering	
Miscellaneous skills, training	
Imagery, optics, microscopy	
Computer skills	
Lab equipment, instruments, analysis	
Farm Business Management	
Problem-solving, critical think	
Nano info, products, industry	
Electronics, mechanical, vocational	
Design, drafting, creative	
Basic employment issues	
Innate, natural talents	
Math	
People skills	
Other	
Research, lab, hands-on experience	
Business skills	
Language skill development	
Basic literacy	

11 Which technical knowledge competencies would you like delivered from nanoscience and nanotechnology education for placement in Agrifood nanotechnology Sector?

Check as many as appropriate.

Technical knowledge competencies	Check
Nanoscale physical phenomena (quantum effects)	
Chemistry:	
Colloidal Chemistry	
Wet Chemistry	
Inorganic Chemistry	
Organic Chemistry	
Molecular Chemistry	
Nano - biology interfaces	

Metallurgy	
Material Science	
Fabrication techniques (Top-down and bottom-up):	
Lithography (E-beam, Optical, Photo, Micro, Stereo, Soft)	
Embossing (Hot, Cold)	
Printing	
Etching (Dry, Wet, Reactive ion, photochemical)	
Plasma Enhanced Chemical Vapor Deposition	
Molecular Beam Epitaxy	
Thermal Evaporation	
E-Beam Evaporation	
Milling (Focused Ion beam)	
Sol Gel	
Microinjection Molding	
Laser Micro Machining	
CNC micromachining	
Bonding and Joining	
Self-Assembled Monolayer	
Layer by Layer	
Chemical Mechanical Polishing	
Characterization and analysis techniques:	
Scanning Electron Microscopy	
Transmission Electron Microscopy	
Scanning Tunneling Microscopy	
Atomic Force Microscopy	
Optical Microscopy	
Fluorescence Microscopy	
Confocal Microscopy	
XDS	
XPS	
SIMS	
X-ray	
Design methodologies and product development	
New materials, properties and their selection	
Near nanoscale devices and structures	
Nanoelectronics	
Photovoltaics and Photonic	
Technical communication (Written and spoken)	
Computational models and software (Modelling, CAD, CAM)	
Health and Safety	
Other (please specify):	

PART IV - IMPACT ON SKILLS

18. Skills gaps arise when the current employees do not fully meet the skills requirements for their job functions. To what extent do job-requirements stemming from developments in nanotechnology currently lead to skill gaps in agrifood industry?
    a) No skill gaps
    b) Limited skill gaps
    c) Substantial skill gaps
    d) Do not know

19. To what extent do you expect developments in nanotechnology to lead to skill gaps in the agrifood sector in the future?

a) No future recruitment problems
b) Limited future recruitment problems
c) Substantial future recruitment problems
d) Do not know

20. What is the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in Nanotechnology?
    a) Increase wages
    b) (Further) automation and mechanization to substitute labor
    c) Try to postpone retirement older employees
    d) Recruiting workers from other sectors, or other countries
    e) Recruiting young people from the education system
    f) Use of specialized agencies/temporary workers/ headhunters
    g) Restructuring the (work) organization
    h) Increase internal job mobility in the company
    i) Outsourcing and off shoring
    j) On the job training
    k) Participation of employees in off the job training and education programs
    l) Stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes)
    m) Other, namely........ ?
    n) Do not know

21. What measure (s) should agrifood businesses take now to address skill needs?
    a) Conducting a Skills Inventory
    b) Applying/seeking funding to address needs
    c) Using outside private consultants/providers to assist
    d) Increasing retention efforts
    e) Developed in-house skills training/mentoring
    f) None
    g) Working with the local educational institutions to provide training and recruiting
    h) Predicting future skills needs
    i) Other (please specify)

22. Do you think the higher education system (Universities, polytechnics, higher vocational education) in the United States is able to fulfill skill needs related to present and future developments in nanotechnology?
    a) To a great extent
    b) Somewhat
    c) Very little
    d) Not at all
    e) Do not know

23. What should be improved within the higher education system to better fulfill skill needs related to developments in nanotechnology? (Please select as many as apply).
    a) Stronger cooperation with companies
    b) Increase the supply of graduates in relevant fields
    c) Start new types of higher level science courses
    d) Improve the theoretical level of education programs on Bachelor/Masters level More possibilities for (part-time) PhD programs
    e) More specialization (i.e. in-depth knowledge of specific domains) within science
    f) Less specialization within science, but more general knowledge of scientific domains within science

g) More attention for personal skills in education
h) More attention for technical developments in non-technical studies
i) More opportunities for training courses of experienced professionals to update skills and acquire new skills
j) Improve international cooperation
k) Other, namely... ?
l) Do not know

24. Do you think the vocational education and training (VET)/Career and Technical Education (CTE) system in the United States is able to fulfill skill needs related to present and future developments in Nanotechnology?
    a) To a great extent
    b) Somewhat
    c) Very little
    d) Not at all
    e) Do not know

25. If relevant, what should be improved within the vocational education and training/Career and Technical Education system to better fulfill skill needs related to developments in Nanotechnology? (Please select as many as apply)
    a) Stronger cooperation with companies
    b) Increase the supply of graduates, especially in relevant fields
    c) Start new types of vocational specializations in the education system
    d) Improve the theoretical level
    e) More attention for personal skills in vocational education
    f) More attention for technical developments in non-technical studies
    g) More opportunities for training courses of experienced professionals to update skills and acquire new skills.
    h) Improve conditions for companies to employ apprentices and interns from the vocational education system
    i) Improve international cooperation
    j) Other, namely..
    k) Do not know

26. What is your opinion regarding the government's role in development of nanotechnology? Select one option.
    a) Industry leads developments, Government involvement is not necessary
    b) Industry takes the initiative and Govt. oversees the nanotech industry
    c) Govt. should co-invest in industry-led nanotechnology developments
    d) Govt. should co-invest heavily & offer strong incentives to industry

27. To what extent will the third sector (NGOs, Advocacy Groups etc.) play in fulfilling skill needs related to development of nanotechnology?
    a) To a great extent
    b) Somewhat
    c) Very little
    d) Not at all
    e) Do not know

28. To what extent will the public play in fulfilling skill needs related to development of nanotechnology?
    a) To a great extent
    b) Somewhat

c) Very little
d) Not at all
e) Do not know

29. Do you have any other suggestions for policy makers which could help to fulfill skill needs related to present and future development in nanotechnology and agrifood nanotechnology development more specifically?

30. Please add any additional comments you may have concerning identified skill gaps or possible future skill needs in the agrifood nanotechnology sector.

31. Thank you for participating in this important project. Please indicate if you like the findings from this survey to be made available to you. In case you would like to receive a copy, please leave your e-mail address: (still warranting anonymity; it will never be possible to trace back individual answers).

Appendix C – IRB Notification and Letters of Invitation

IRB - Exempt Study Notification

FROM: irb@umn.edu
TO : bgreiman@umn.edu, yawso003@umn.edu,
SUBJECT: 1203E11023 - PI Yawson - IRB - Exempt Study Notification

The IRB: Human Subjects Committee determined that the referenced study is exempt from review under federal guidelines 45 CFR Part 46.101(b) category #2 SURVEYS/INTERVIEWS; STANDARDIZED EDUCATIONAL TESTS; OBSERVATION OF PUBLIC BEHAVIOR.

Study Number: 1203E11023

Principal Investigator: Robert Yawson

Title(s): Systems Approach to Skill Needs Identification for Agrifood Nanotechnology

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This e-mail confirmation is your official University of Minnesota HRPP notification of exemption from full committee review. You will not receive a hard copy or letter.

This secure electronic notification between password protected authentications has been deemed by the University of Minnesota to constitute a legal signature.

The study number above is assigned to your research. That number and the title of your study must be used in all communication with the IRB office.

Research that involves observation can be approved under this category without obtaining consent.

SURVEY OR INTERVIEW RESEARCH APPROVED AS EXEMPT UNDER THIS CATEGORY IS LIMITED TO ADULT SUBJECTS.

This exemption is valid for five years from the date of this correspondence and will be filed inactive at that time. You will receive a notification prior to inactivation. If this research will extend beyond five years, you must submit a new application to the IRB before the study's expiration date.

Upon receipt of this email, you may begin your research. If you have questions, please call the IRB office at (612) 626-5654.

You may go to the View Completed section of eResearch Central at http://eresearch.umn.edu/ to view further details on your study.

The IRB wishes you success with this research.

We have created a short survey that will only take a couple of minutes to complete. The questions are basic but will give us guidance on what areas are showing improvement and what areas we need to focus on: https://umsurvey.umn.edu/index.php?sid=94693&lang=um

Study Participant Consent Letter

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Department of Organizational Leadership, Policy, and Development
College of Education and Human Development

330 Wulling Hall
86 Pleasant Street S.E.
Minneapolis, MN 55455-0221
Office: 612-624-1006
Fax: 612-624-3377
http://cehd.umn.edu/OLPD

Consent Form: Systems Approach to Skill Needs Identification for Agrifood Nanotechnology

You are invited to be in this study on "Systems Approach to Skill Needs Identification for Agrifood Nanotechnology". You were selected to participate because you have been identified as Expert/Stakeholder in the emerging agrifood nanotechnology sector. We ask that you read this form and ask questions before agreeing to participate in the study. This study is conducted by Robert M. Yawson, a doctoral candidate in the Organizational Leadership, Policy and Development Department at the University of Minnesota with dual specializations in Agriculture, Food, and Environmental Education; and Human Resource Development and Workforce Education.

The purpose of the study is to identify skill needs for the emerging agrifood nanotechnology sector and to determine how agricultural education can contribute to human resource and workforce development for this emerging sector. If you decide to participate, you will be asked to complete some surveys about skill needs for agrifood nanotechnology and/or participate in a phone interview about skill needs and educational requirements for agrifood nanotechnology.

The survey will take about 15 minutes to complete and the phone interview will be on a mutually agreed upon time and should last about 30 minutes. The phone interview will be audio taped so that I can accurately reflect on what is discussed. The tapes will be transcribed and analyzed by me and they will then be destroyed.

Although you probably won't benefit directly from participating in this study, we hope that others in the community/society in general will benefit. Participation is confidential. Study information will be kept in a secure location at the University of Minnesota. The results of the study may be published or presented at professional meetings, but your identity will not be revealed. Participation is anonymous. There are no known or anticipated or potential risks in participating in this study. We want to assure you that all of your questionnaire responses will be kept completely confidential.

Contact Information
We will be happy to answer any questions you have about the study. You may contact me at 612 860 0541 and yawso003@umn.edu or my faculty advisor, Brad Greiman, at 612-624-5644 and bgreiman@umn.edu if you have study related questions or problems. If you have any questions about your rights as a research participant, you may contact the Research Integrity & Oversight Programs Office of the University of Minnesota at 612.625.9057 or riop@umn.edu.

Statement of Consent:
I have read the above information. I consent to participate in the study.

Letter of Invitation to Experts

Dear ……

Invitation to Participate in a Study on "Systems Approach to Skill Needs Identification for Agrifood Nanotechnology"

My name is Robert M. Yawson. I am a doctoral candidate in the Organizational Leadership, Policy and Development Department at the University of Minnesota with dual specializations in Agriculture, Food, and Environmental Education; and Human Resource Development and Workforce Education. I am conducting a research study as part of the requirements of my PhD degree in Organizational Leadership, Policy and Development, and I would like to invite you to participate.

I am studying to identify skill needs for the emerging agrifood nanotechnology sector and to determine how agricultural education can contribute to human resource and workforce development for this emerging sector. You have been identified as an expert and your contribution will be valuable to this study. If you decide to participate, you will be asked to complete some surveys about skill needs for agrifood nanotechnology and/or participate in a phone interview about skill needs and educational requirements for agrifood nanotechnology.

The survey will take about 15 minutes to complete and the phone interview will be on a mutually agreed upon time and should last about 30 minutes. The phone interview will be audio taped so that I can accurately reflect on what is discussed. The tapes will be transcribed and analyzed by me and they will then be destroyed.

Although you probably won't benefit directly from participating in this study, we hope that others in the community/society in general will benefit. Participation is confidential. Study information will be kept in a secure location at the University of Minnesota. The results of the study may be published or presented at professional meetings, but your identity will not be revealed. Participation is anonymous.

We will be happy to answer any questions you have about the study. You may contact me at 612 860 0541 and yawso003@umn.edu or my faculty advisor, Brad Greiman, at 612-624-5644 and bgreiman@umn.edu if you have study related questions or problems. If you have any questions about your rights as a research participant, you may contact the Research Integrity & Oversight Programs Office of the University of Minnesota at 612.625.9057 or riop@umn.edu.

Thank you for your consideration. The Consent Form is also attached to this email. It does not require a signature, but we ask that you raise any questions you may have about it before agreeing to participate.

If you would like to participate, please click on this **link** to proceed to the survey. Please note: If you do not wish to receive further emails from me, please click the link below, and you will be automatically removed from my mailing list. https://www.surveymonkey.com/optout.aspx

With kind regards,

Robert M. Yawson

Customizable Letter to Stakeholders

Dear ……

Invitation to Participate in a Study on "Systems Approach to Skill Needs Identification for Agrifood Nanotechnology"

My name is Robert M. Yawson. I am a doctoral candidate in the Organizational Leadership, Policy and Development Department at the University of Minnesota with dual specializations in Agriculture, Food, and Environmental Education; and Human Resource Development and Workforce Education. I am conducting a research study as part of the requirements of my PhD degree in Organizational Leadership, Policy and Development, and I would like to invite your

Department/Institute/organization to participate as a key stakeholder in the agrifood nanotechnology sector. I understand that your organization may not be directly in the area of Agriculture and Food production, however, your services are part of the agrifood VALUE chain, and the contribution you have made to nanotechnology education and workforce development in general will be valuable to this study.

I am studying to identify skill needs for the emerging agrifood nanotechnology sector and to determine how agricultural education can contribute to human resource and workforce development for this emerging sector. If you decide to participate, you will be asked to complete a survey about skill needs and educational requirements for agrifood nanotechnology. The survey will take about 15 minutes to complete.

Although you probably won't benefit directly from participating in this study, we hope that others in the community/society in general will benefit. Participation is confidential. Study information will be kept in a secure location at the University of Minnesota. The results of the study may be published or presented at professional meetings, but the identity of your organization will not be revealed. Participation is anonymous.

We will be happy to answer any questions you have about the study. You may contact me at 612 860 0541 and yawso003@umn.edu or my faculty advisor, Brad Greiman, at 612-624-5644 and bgreiman@umn.edu if you have study related questions or problems. If you have any questions about your rights as a research participant, you may contact the Research Integrity & Oversight Programs Office of the University of Minnesota at 612.625.9057 or riop@umn.edu.

Thank you for your consideration. The Consent Form is also attached to this email. It does not require a signature, but we ask that you raise any questions you may have about it before agreeing to participate.

If you would like to participate, please click on this **link** to proceed to the survey. If you do not wish to receive further emails from me, please click the link below, and you will be automatically removed from my mailing list. https://www.surveymonkey.com/optout.aspx

With kind regards,

Robert M. Yawson

Appendix D –Employability Skills and Competencies

Table D1: *Average Rating of Employability Skills and Competencies*

Skills and Competencies	I	II	III	IV	V	VI	VII	VIII	IX	X
Problem-solving, critical thinking	4.00	4.46	4.42	4.14	4.33	3.80	4.14	4.50	4.26	4.22
New Product Innovation	4.22	4.15	4.25	3.86	4.33	4.25	3.86	4.25	4.14	4.15
Nano info, products, industry	3.78	4.17	4.30	4.14	4.33	4.20	4.14	4.00	4.18	4.13
Research and Development Management	4.35	4.02	4.02	4.29	4.00	3.60	4.29	4.50	4.10	4.13
Environmental and Sustainability	4.59	4.00	4.25	4.00	4.33	3.80	4.00	3.50	3.98	4.06
Lab equipment, instruments, analysis	4.00	3.98	3.83	3.57	4.33	4.00	3.57	4.50	3.97	3.97
Ethics	4.27	4.43	4.49	3.86	4.00	2.80	3.86	4.00	3.92	3.96
Risk Assessment and Management	4.26	3.70	3.77	4.14	4.00	3.60	4.14	4.00	3.91	3.95
Chemistry, physics, materials	4.48	3.94	3.70	3.86	4.33	3.80	3.86	3.50	3.86	3.93
Technology strategy	3.87	3.69	4.04	3.86	3.67	4.00	3.86	4.25	3.91	3.90
Basic literacy	3.70	4.02	4.04	3.86	4.33	3.40	3.86	4.00	3.93	3.90
Research, lab, hands-on experience	4.09	4.04	3.91	3.43	4.33	3.40	3.43	4.25	3.83	3.86
Public Communication	4.17	4.17	3.38	4.14	3.33	3.40	4.14	4.00	3.80	3.84
Team working	3.48	3.98	3.98	4.00	4.33	2.60	4.00	4.00	3.84	3.80
Leadership	3.78	3.96	4.06	3.43	4.00	3.20	3.43	4.25	3.76	3.76
Project Management	3.36	3.87	4.04	3.71	4.00	3.40	3.71	4.00	3.82	3.76
Computer skills	3.78	4.15	3.98	3.14	4.33	4.20	3.14	3.25	3.74	3.75
Engineering	4.27	3.83	3.75	3.29	4.33	3.20	3.29	3.75	3.63	3.71
Entrepreneurship	3.96	3.83	3.72	3.14	4.00	3.60	3.14	4.00	3.63	3.67
Business skills	3.50	3.55	3.54	3.00	4.00	4.00	3.00	4.50	3.66	3.64
Technology marketing	3.57	3.69	3.46	3.57	3.33	3.60	3.57	4.25	3.64	3.63
Math	3.48	4.04	3.77	2.71	4.00	4.00	2.71	4.25	3.64	3.62
Verbal Communication	3.57	4.02	3.81	3.43	4.00	2.60	3.43	3.75	3.58	3.58
Technology policy	3.57	3.51	3.54	3.43	4.00	3.60	3.43	3.50	3.57	3.57
Intellectual property	3.87	3.60	3.81	3.00	3.67	4.00	3.00	3.50	3.51	3.56
Imagery, optics, microscopy	3.70	3.65	3.44	2.86	4.50	3.40	2.86	3.50	3.46	3.49
Manufacturing skills	3.70	3.47	3.23	3.29	4.00	3.20	3.29	3.50	3.42	3.46
Lateral thinking	3.39	3.60	3.54	3.14	4.00	3.60	3.14	3.25	3.47	3.46
Finance (Start-up Venture and Corporate)	3.43	3.72	3.52	2.86	3.33	4.00	2.86	3.75	3.43	3.43
People skills	3.45	3.79	3.72	2.86	4.00	3.00	2.86	3.75	3.42	3.43
Legal	3.57	3.77	3.60	2.86	3.67	2.40	2.86	4.25	3.34	3.37
Electronics, mechanical, vocational	3.04	3.94	3.49	2.71	4.00	2.60	2.71	4.00	3.35	3.31
Design, drafting, creative	2.78	3.68	3.38	2.57	3.67	3.00	2.57	4.00	3.27	3.21
Hardware	3.43	3.55	3.13	2.71	4.00	2.80	2.71	3.25	3.17	3.20
Miscellaneous skills, training	2.96	3.09	2.89	3.14	4.50	2.60	3.14	3.25	3.23	3.20
Farm Business Management	3.14	2.91	3.35	3.00	3.67	2.40	3.00	4.00	3.19	3.18
People friendliness	3.17	3.57	3.21	2.71	4.00	2.40	2.71	3.50	3.16	3.16

Innate, natural talents	2.74	3.09	3.00	2.86	3.67	3.00	2.86	3.75	3.17	3.12
Language skill development	3.09	3.21	3.24	2.29	3.33	2.80	2.29	3.25	2.91	2.94
Basic employment issues	2.57	3.36	2.94	2.29	4.00	2.40	2.29	3.50	2.97	2.92

Notes: Experts = I; AAAE = II; AHRD = III; GOVT = IV; EDUC = V; NAWDP = VI; IFT = VII; MNAGC = VIII; Stakeholder Total = IX; Overall Total = X

Appendix E – Agrifood Career Pathways and Occupations

Career Pathway	Code	Occupation
Agribusiness Systems	25-1041.00	Agricultural Sciences Teachers, Postsecondary
	27-4011.00	Audio and Video Equipment Technicians
	13-1021.00	Buyers and Purchasing Agents, Farm Products **Green**
	25-9021.00	Farm and Home Management Advisors
	13-1074.00	Farm Labor Contractors
	11-3031.02	Financial Managers, Branch or Department **Bright Outlook**
	19-1012.00	Food Scientists and Technologists
	27-1024.00	Graphic Designers
	27-3022.00	Reporters and Correspondents
	41-4011.00	Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products
Animal Systems	19-4011.00	Agricultural and Food Science Technicians
	25-1041.00	Agricultural Sciences Teachers, Postsecondary
	19-4011.01	Agricultural Technicians
	45-2021.00	Animal Breeders
	19-1011.00	Animal Scientists
	39-2011.00	Animal Trainers
	11-9013.03	Aquacultural Managers
	25-9021.00	Farm and Home Management Advisors
	11-9013.02	Farm and Ranch Managers
	11-9013.00	Farmers, Ranchers, and Other Agricultural Managers
	45-2093.00	Farmworkers, Farm, Ranch, and Aquacultural Animals
	45-1011.08	First-Line Supervisors of Animal Husbandry and Animal Care Workers
	45-1011.06	First-Line Supervisors of Aquacultural Workers
	45-1011.00	First-Line Supervisors of Farming, Fishing, and Forestry Workers
	41-1011.00	First-Line Supervisors of Retail Sales Workers
	19-4011.02	Food Science Technicians
	45-3021.00	Hunters and Trappers
	39-2021.00	Nonfarm Animal Caretakers
	29-1131.00	Veterinarians
	31-9096.00	Veterinary Assistants and Laboratory Animal Caretakers
	29-2056.00	Veterinary Technologists and Technicians
	19-1023.00	Zoologists and Wildlife Biologists
Environmental Service Systems	13-1041.01	Environmental Compliance Inspectors
	17-3025.00	Environmental Engineering Technicians
	17-2081.00	Environmental Engineers

	19-4091.00	Environmental Science and Protection Technicians, Including Health
	47-4041.00	Hazardous Materials Removal Workers
	29-9011.00	Occupational Health and Safety Specialists
	29-9012.00	Occupational Health and Safety Technicians
	37-2021.00	Pest Control Workers
	51-9199.01	Recycling and Reclamation Workers
	53-1021.01	Recycling Coordinators
	49-9021.02	Refrigeration Mechanics and Installers
	53-7081.00	Refuse and Recyclable Material Collectors
	51-8031.00	Water and Wastewater Treatment Plant and System Operators
Food Products and Processing Systems	19-4011.00	Agricultural and Food Science Technicians
	45-2011.00	Agricultural Inspectors
	25-1041.00	Agricultural Sciences Teachers, Postsecondary
	19-4011.01	Agricultural Technicians
	11-9013.03	Aquacultural Managers
	51-3021.00	Butchers and Meat Cutters
	13-1021.00	Buyers and Purchasing Agents, Farm Products
	19-4031.00	Chemical Technicians
	15-1151.00	Computer User Support Specialists
	11-9013.02	Farm and Ranch Managers
	11-9013.00	Farmers, Ranchers, and Other Agricultural Managers
	45-1011.07	First-Line Supervisors of Agricultural Crop and Horticultural Workers
	45-1011.06	First-Line Supervisors of Aquacultural Workers
	45-1011.00	First-Line Supervisors of Farming, Fishing, and Forestry Workers
	45-1011.05	First-Line Supervisors of Logging Workers
	43-1011.00	First-Line Supervisors of Office and Administrative Support Workers
	51-3091.00	Food and Tobacco Roasting, Baking, and Drying Machine Operators and Tenders
	51-3092.00	Food Batchmakers
	51-3093.00	Food Cooking Machine Operators and Tenders
	19-4011.02	Food Science Technicians
	19-1012.00	Food Scientists and Technologists
	45-2041.00	Graders and Sorters, Agricultural Products
	51-3022.00	Meat, Poultry, and Fish Cutters and Trimmers
	39-2021.00	Nonfarm Animal Caretakers
	43-9071.00	Office Machine Operators, Except Computer
	37-2021.00	Pest Control Workers
	51-3023.00	Slaughterers and Meat Packers

Natural Resources Systems	11-9013.03	Aquacultural Managers
	25-1042.00	Biological Science Teachers, Postsecondary
	53-5021.00	Captains, Mates, and Pilots of Water Vessels
	17-1021.00	Cartographers and Photogrammetrists
	49-9092.00	Commercial Divers
	19-1031.00	Conservation Scientists
	47-5041.00	Continuous Mining Machine Operators
	53-7011.00	Conveyor Operators and Tenders
	47-5011.00	Derrick Operators, Oil and Gas
	47-5021.00	Earth Drillers, Except Oil and Gas
	17-3029.00	Engineering Technicians, Except Drafters, All Other
	19-4091.00	Environmental Science and Protection Technicians, Including Health
	25-1053.00	Environmental Science Teachers, Postsecondary
	19-2041.00	Environmental Scientists and Specialists, Including Health
	53-7032.00	Excavating and Loading Machine and Dragline Operators
	47-5031.00	Explosives Workers, Ordnance Handling Experts, and Blasters
	45-4021.00	Fallers
	45-1011.06	First-Line Supervisors of Aquacultural Workers
	47-1011.00	First-Line Supervisors of Construction Trades and Extraction Workers
	45-1011.00	First-Line Supervisors of Farming, Fishing, and Forestry Workers
	33-3031.00	Fish and Game Wardens
	45-3011.00	Fishers and Related Fishing Workers
	19-4093.00	Forest and Conservation Technicians
	45-4011.00	Forest and Conservation Workers
	19-1032.00	Foresters
	53-7071.00	Gas Compressor and Gas Pumping Station Operators
	51-8092.00	Gas Plant Operators
	19-4041.00	Geological and Petroleum Technicians
	19-4041.02	Geological Sample Test Technicians
	19-4041.01	Geophysical Data Technicians
	47-5081.00	Helpers--Extraction Workers
	53-7051.00	Industrial Truck and Tractor Operators
	53-7033.00	Loading Machine Operators, Underground Mining
	45-4023.00	Log Graders and Scalers
	45-4022.00	Logging Equipment Operators
	17-3027.00	Mechanical Engineering Technicians
	47-5042.00	Mine Cutting and Channeling Machine Operators
	53-7111.00	Mine Shuttle Car Operators
	11-9121.00	Natural Sciences Managers

	19-1031.03	Park Naturalists
	51-8093.00	Petroleum Pump System Operators, Refinery Operators, and Gaugers
	51-8099.00	Plant and System Operators, All Other
	19-4099.02	Precision Agriculture Technicians
	53-7072.00	Pump Operators, Except Wellhead Pumpers
	19-1031.02	Range Managers
	25-1193.00	Recreation and Fitness Studies Teachers, Postsecondary
	39-9032.00	Recreation Workers
	53-7081.00	Refuse and Recyclable Material Collectors
	47-5051.00	Rock Splitters, Quarry
	47-5061.00	Roof Bolters, Mining
	47-5012.00	Rotary Drill Operators, Oil and Gas
	47-5071.00	Roustabouts, Oil and Gas
	51-7041.00	Sawing Machine Setters, Operators, and Tenders, Wood
	47-5013.00	Service Unit Operators, Oil, Gas, and Mining
	53-5021.01	Ship and Boat Captains
	19-1031.01	Soil and Water Conservationists
	53-7121.00	Tank Car, Truck, and Ship Loaders
	53-7073.00	Wellhead Pumpers
	19-1023.00	Zoologists and Wildlife Biologists
Plant Systems	19-4011.00	Agricultural and Food Science Technicians
	25-1041.00	Agricultural Sciences Teachers, Postsecondary
	19-4011.01	Agricultural Technicians
	19-1011.00	Animal Scientists
	11-9013.03	Aquacultural Managers
	19-1021.00	Biochemists and Biophysicists
	19-3011.00	Economists
	25-9021.00	Farm and Home Management Advisors
	11-9013.02	Farm and Ranch Managers
	49-3041.00	Farm Equipment Mechanics and Service Technicians
	11-9013.00	Farmers, Ranchers, and Other Agricultural Managers
	45-2092.02	Farmworkers and Laborers, Crop
	45-2092.00	Farmworkers and Laborers, Crop, Nursery, and Greenhouse
	45-2093.00	Farmworkers, Farm, Ranch, and Aquacultural Animals
	45-1011.07	First-Line Supervisors of Agricultural Crop and Horticultural Workers
	45-1011.08	First-Line Supervisors of Animal Husbandry and Animal Care Workers
	45-1011.06	First-Line Supervisors of Aquacultural Workers
	45-1011.00	First-Line Supervisors of Farming, Fishing, and Forestry Workers

	37-1012.00	First-Line Supervisors of Landscaping, Lawn Service, and Groundskeeping Workers
	45-1011.05	First-Line Supervisors of Logging Workers
	41-1011.00	First-Line Supervisors of Retail Sales Workers
	27-1023.00	Floral Designers
	19-4011.02	Food Science Technicians
	19-1012.00	Food Scientists and Technologists
	19-1032.00	Foresters
	37-3019.00	Grounds Maintenance Workers, All Other
	37-3011.00	Landscaping and Groundskeeping Workers
	11-9013.01	Nursery and Greenhouse Managers
	45-2092.01	Nursery Workers
	37-3012.00	Pesticide Handlers, Sprayers, and Applicators, Vegetation
	41-2031.00	Retail Salespersons
	19-1013.00	Soil and Plant Scientists
	19-1031.01	Soil and Water Conservationists
	37-3013.00	Tree Trimmers and Pruners
Power, Structural and Technical Systems	45-2091.00	Agricultural Equipment Operators
	25-1041.00	Agricultural Sciences Teachers, Postsecondary
	49-3011.00	Aircraft Mechanics and Service Technicians
	49-3041.00	Farm Equipment Mechanics and Service Technicians
	49-3042.00	Mobile Heavy Equipment Mechanics, Except Engines
	41-2022.00	Parts Salespersons

Appendix F – Agrifood Systems Model Appendix

Functional Relations within the Agrifood Systems Model

(01) "Agrifood Labor Market Intermediaries (LMI)"=A FUNCTION OF ("Agrifood Labor Market Intermediaries (LMI)”,"Education & Training (Higher Education; CTE and VET; K-12)","Employable Workforce (EW)")"Agrifood Labor Market Intermediaries (LMI)"=1*"Education & Training (Higher Education; CTE and VET; K-12)"
Units: Dmnl

(02) Agrifood Nanotechnology Education=A FUNCTION OF (Agrifood Nanotechnology Education, Educational Policies Enacted, Educational Reforms Done) Agrifood Nanotechnology Education= INTEG (INTEGER (Educational Policies Enacted-Educational Reforms Done),)
Units: Dmnl

(03) Agrifood Nanotechnology Workforce Base=A FUNCTION OF (Agrifood Nanotechnology Workforce Base, Workforce Demand, Workforce Supply) Agrifood Nanotechnology Workforce Base= INTEG (INTEGER (Workforce Supply-Workforce Demand),)
Units: Dmnl

(04) "Education & Training (Higher Education; CTE and VET; K-12)” = A FUNCTION OF ("Type of Education (TOE)") "Education & Training (Higher Education; CTE and VET; K-12)"="Type of Education (TOE)"*1
Units: Dmnl

(05) Educational Policies Enacted=A FUNCTION OF (Educational Policies Enacted, Agrifood Nanotechnology Workforce Base, “Effective Education (EE)", NanoSkills Needs ,"Number of Educational Policies Enacted (NEP)") Educational Policies Enacted= Agrifood Nanotechnology Workforce Base*"Effective Education (EE)"*NanoSkills Needs *"Number of Educational Policies Enacted (NEP)"
Units: Year

(06) Educational Reforms Done=A FUNCTION OF (Educational Reforms Done, Agrifood Nanotechnology Education, “Education & Training (Higher Education; CTE and VET; K-12)","Existing Educational Infrastructure (EEI)") Educational Reforms Done= Agrifood Nanotechnology Education*"Education & Training (Higher Education; CTE and VET; K-12)" *"Existing Educational Infrastructure (EEI)"
Units: **undefined**

(07) "Effective Education (EE)” = A FUNCTION OF (Funding of Nanotechnology, NanoSkills Needs) "Effective Education (EE)"
Units: **undefined**

(08) "Employable Workforce (EW)” = A FUNCTION OF (“Education & Training (Higher Education; CTE and VET; K-12)”, Educational Policies Enacted, Educational Reforms Done,"R&D Activity")
Units: **undefined**

(09) "Existing Educational Infrastructure (EEI)" = A FUNCTION OF (Funding of Nanotechnology)
Units: **undefined**

(10) FINAL TIME = 7
Units: Year

The final time for the simulation.

(11) Funding of Nanotechnology=A FUNCTION OF (Funding of Nanotechnology) Funding of Nanotechnology= INTEG (,)
Units: Year

(12) INITIAL TIME = 0
Units: Year
The initial time for the simulation.

(13) NanoSkills Acquired=A FUNCTION OF(NanoSkills Acquired, "Education & Training (Higher Education; CTE and VET; K-12)" ,"Effective Education (EE)","Employable Workforce (EW)","Type of Education (TOE)")NanoSkills Acquired="Effective Education (EE)"*"Employable Workforce (EW)"*"Type of Education (TOE)" *"Education & Training (Higher Education; CTE and VET; K-12)"
Units: **undefined**

(14) "NanoSkills Acquisition Rate (NSAR)" = A FUNCTION OF (Workers)
Units: **undefined**

(15) NanoSkills Needs = A FUNCTION OF ("NanoSkills Acquisition Rate (NSAR)"
, Skills Gap)
Units: **undefined**

(16) "Number of Educational Policies Enacted (NEP)" = A FUNCTION OF ( )
Units: **undefined**

(17) "R&D Activity" = A FUNCTION OF ("Education & Training (Higher Education; CTE and VET; K-12)", Funding of Nanotechnology)
Units: **undefined**

(18) Recommendations = A FUNCTION OF ("Education & Training (Higher Education; CTE and VET; K-12)","Employable Workforce (EW)", Funding of Nanotechnology)
Units: **undefined**

(19) SAVEPER = TIME STEP
Units: Year [0,]
The frequency with which output is stored.

(20) Skills Gap=A FUNCTION OF (Skills Gap, NanoSkills Acquired, NanoSkills Needs)
Skills Gap= INTEG (INTEGER (NanoSkills Acquired-NanoSkills Needs),)
Units: Dmnl

(21) TIME STEP = 1
Units: Year [0,]
The time step for the simulation.

(22) "Type of Education (TOE)" = A FUNCTION OF (Funding of Nanotechnology)
Units: **undefined**

(23) Workers = A FUNCTION OF ("Existing Educational Infrastructure (EEI)")
Units: **undefined**

(24) Workforce Demand = A FUNCTION OF (Agrifood Nanotechnology Workforce Base ,"Employable Workforce (EW)","R&D Activity")

Workforce Demand=Agrifood Nanotechnology Workforce Base*"Employable Workforce (EW)"
Units: **undefined**

(25) Workforce Supply = A FUNCTION OF (“Agrifood Labor Market Intermediaries (LMI)" , Recommendations, Workers) Workforce Supply="Agrifood Labor Market Intermediaries (LMI)"*Recommendations*Workers
Units: **undefined**

Full List of Loops Emanating from “Skills Gap” Variable

Loop Number 1 of length 1
Skills Gap
NanoSkills Needs

Loop Number 2 of length 3
Skills Gap
NanoSkills Needs
Effective Education (EE)
NanoSkills Acquired

Loop Number 3 of length 4
Skills Gap
NanoSkills Needs
Educational Policies Enacted
Employable Workforce (EW)
NanoSkills Acquired

Loop Number 4 of length 5
Skills Gap
NanoSkills Needs
Effective Education (EE)
Educational Policies Enacted
Employable Workforce (EW)
NanoSkills Acquired

Loop Number 5 of length 6
Skills Gap
NanoSkills Needs
Educational Policies Enacted
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
NanoSkills Acquired

Loop Number 6 of length 7
Skills Gap
NanoSkills Needs
Effective Education (EE)
Educational Policies Enacted
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
NanoSkills Acquired

Full List of Loops Emanating from “ANE” Variable

Loop Number 1 of length 1
Agrifood Nanotechnology Education
Educational Reforms Done

Loop Number 2 of length 5
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Workforce Demand
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted

Loop Number 3 of length 6
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Recommendations
Workforce Supply
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted

Loop Number 4 of length 6
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
NanoSkills Acquired
Skills Gap
NanoSkills Needs
Educational Policies Enacted

Loop Number 5 of length 6
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Agrifood Labor Market Intermediaries (LMI)
Workforce Supply
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted

Loop Number 6 of length 7
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
NanoSkills Acquired
Skills Gap
NanoSkills Needs
Effective Education (EE)
Educational Policies Enacted

Full List of Loops Emanating from "ANWB" Variable

Loop Number 1 of length 1
Agrifood Nanotechnology Workforce Base
Workforce Demand

Loop Number 2 of length 3
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Employable Workforce (EW)
Workforce Demand

Loop Number 3 of length 4
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Employable Workforce (EW)
Recommendations
Workforce Supply

Loop Number 4 of length 4
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Employable Workforce (EW)
Agrifood Labor Market Intermediaries (LMI)
Workforce Supply

Loop Number 5 of length 5
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Workforce Demand

Loop Number 6 of length 6
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Recommendations
Workforce Supply

Loop Number 7 of length 6
Agrifood Nanotechnology Workforce Base
Educational Policies Enacted
Agrifood Nanotechnology Education
Educational Reforms Done
Employable Workforce (EW)
Agrifood Labor Market Intermediaries (LMI)
Workforce Supply

Appendix G – Proposed Freshman Year Agrifood Nanotechnology Syllabus

Course Description

This course is an introduction to nanoscience and nanotechnology applications in agriculture food and natural resource sciences. This course is designed to stimulate the interest of agricultural, food, and environment science students to engage in the study and exploration of nanoscience and its applications in agriculture and food industry from early stages of their training. An important part of the course will involve developing an understanding of what nanotechnology and nanoscience is about and the implication for the future of agriculture, food, and environment. The course will provide an opportunity for students to visit nanotechnology laboratories at the mechanical engineering department and elsewhere and also listen to experts as guest speakers.

Course Goals

Upon completion of in-class instruction, class activities, exams, site visits, and personal study and reflection, the student is expected to have achieved or increased their ability:

1. To survey the current state of the art of nanoscale science and technology research and its applications in agriculture and food systems;
2. To examine broad societal issues such as education and workforce training, environmental implications, and safety, ethical, legal and economic considerations toward development and deployment of nanoscience in food and agriculture;
3. To envision the challenges and opportunities that advancements in nanoscale science and technology may bring about to further enhance food quality, value, safety and biosecurity.

Exams and Grading

There will be one midterm exam and one final exam. These will consist of multiple-choice, true-false, and *short* questions. All exams will be taken online using Moodle and it will be open-book exams. All students *must* take all the exams in the main class sections. All exams are comprehensive: the midterms will cover all the material before them, and the final will cover all material.

Grading Scale

Current Events Summaries	100 points	Grading Scale A 100-94; A- 93-90 B+ 89-87; B 86-83, B- 82-80 C+ 79-77; C 76-73; C-72-70 D+ 69-67; D 66-63; D- 62-60 F: <60 (to calculate a final grade, divide the total points by 400. For example, 340 final points over the total 400 possible would be .85, or 85%, a B)
Site Visit Memo	50 points	
Class participation	50 points	
Midterm and Final Examination	200 points	
Total possible points	400 points	

Course Assignment Description

I. *Current Events (100 points total):* Every 1st day of meeting in the week is current events day. Every student will be expected to read and write a summary of a newspaper article, popular science magazines features, or an internet site dealing with some aspect of nanotechnology. Due to its evolving nature, nanotechnology is always in the news. This will help the students to learn and enhance their critical and analytical thinking skills. Not more than 500 words.

II. *Site visit Memo (50 points; due a week after each visit):* Students will be made to write one page memo describing the field experience after visiting a nanotechnology laboratory. There will be two of such visits. This will help the students envision what is actually meant by nanotechnology in reality.

III. *Midterm and Final Examination (100 points each):* The midterm and final examinations is designed to test the competency of every student in what has been learned. The exams will include multiple choice, short answer, and true/false questions. This will help students to be able to cement their understanding of the various topics discussed.

Course Outline

1. **Introduction to Nanoscience and nanotechnology**

   The introductory section of the course is designed to introduce students to:

   1.1 What nanoscience and nanotechnology is
   1.2 History of nanoscience and nanotechnology, timeline and milestones,
   1.3 Overview of different nanomaterials available,
   1.4 Potential uses of nanomaterials in electronics, robotics, computers, sensors in textiles, sports equipment, mobile electronic devices, vehicles and transportation.
   1.5 Medical and agrifood applications of nanomaterials.

2. **Worldwide Research and Development in Food Nanotechnology**

   The move from fundamental research to useful applications in agriculture, animal health, environment, and food is emerging but is faced with some challenges that require further study. This section of the course will provide students with an overview of the state of the art for food nanotechnology research in globally.

3. **Societal Considerations for Food Nanotechnology**

   This section will introduce students to various issues of societal concerns for nanotechnology application in food, animal health and the environment. The specific topics will include:

   3.1 Consumer acceptance of agrifood nanotechnology
   3.2 Nanotechnology and Society
   3.3 Toxicological Impacts of Nanotechnology
   3.4 Green Nanotechnology for Food Packaging
   3.5 Nanoscience Education

4. **Nanotechnology Research for Agriculture and Food Systems in USA**

   The United States has invested more money in nanotechnology research than any other country. This section will introduce students to various research programs around the country, both public and private research.

5. **Potential Applications for Food Nanotechnology**

   Students will be introduced to current and potential applications for agrifood nanotechnology

   5.1 Improving Food Safety, Biosecurity, and Product Traceability
   5.2 Better Nutrient Delivery Mechanisms in Food
   5.3 Nanomaterials to Enhance Packaging Performance
   5.4 Implications of Nanotechnology for Food Processing

6. **Research Needs Identified**

   The final section of this course will equip students to see broadly what lies ahead and the various research needs:

   6.1 Fundamental Knowledge
   6.2 Instrumentation, Characterization and Standards
   6.3 Sensors and Sensing Devices and Systems
   6.4 Product Development
   6.5 Nutrition and Health Research
   6.6 Environmental Research
   6.7 Safety, Ethics and Regulatory Issues
   6.8 Education and Communication